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*.

Membership rates:

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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.

Preparing your manuscript.

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Front cover image: Composite skeleton of a dodo, from 1865 excavations, Mauritius. NMING:F21700. (© National Museum of Ireland)

NatSCA Committee

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Editorial

Jan Freedman

Welcome to Volume 10 of the *Journal of Natural Science Collections.* Volume 9 was a special online only Volume, with several papers focusing on decolonising collections. It has been another difficult year for many of us working in museums due to the ongoing pandemic. Once again I am extremely grateful to all the authors and the reviewers for their time, their patience, and their continuous hard work to get all the articles in this Volume to such a high standard. Thank you to the Editorial board for their hard work on ensuring all the articles were expertly reviewed: Paolo Viscardi, Rob Huxley, and Bethany Palumbo. And thank you to all the reviewers who have given so much of their time to carefully go through the articles and provide constructive feedback to improve them for publication.

This Volume can be divided into five sections: decolonising collections, collections research, conservation, displays, and using collections. In the first article **Selby and Robbins** examine mineral displays in museums and how they have failed to represent Western colonialism. The article examines the history of collecting and what we can do now to address the human processes involved with these collections.

In the next section, focusing on collections research **Oliver** examines the mollusc collection at Doncaster Museum and Art Gallery, highlighting the importance of regional museum collections and their collections, not only for research but for the local stories that they can tell. Wildman *et al.* use museum collections along with other resources to look at the historic distribution of the chequered skipper butterfly *Carterocephalus palaemon* (Pallas, 1771), which was declared extinct in England in 1976. This important research, using collections from dozens of museums, highlights how collections can be used to look at other at risk species, and help protect their habitats. In the final paper in this section, **Monaghan** examines the history of the composite dodo (*Raphus cucullatus* (Linnaeus, 1758)) skeleton at The National Museum of Ireland – Natural History, researching the complicated history of it's acquisition.

The next section includes two papers focusing on conservation. **Granget, Dangeon and Brambilla** provide detailed experiments examining the loss of colour in spirit preserved botanical specimens, highlighting the best preservatives for different botanical specimens. **Priyan, Seeman and Jose** discuss an unusual discovery of mites found inside the eye of the butterfly the tropical tiger moth *Asota caricae* Fabricius 1775.

In the next section focusing on displays, **Freedman and Conway** discuss the procedures they undertook to develop a case specifically designed to display 1140 spirit preserved specimens, with the safety of the collections, staff and visitors in mind. **Wade** explores using contemporary art with natural history collections to highlight the environmental crisis, using several case studies.

The final section focuses on using collections. **Finkle and Maiers** provide case studies from their work with students at the Werner Wildlife Museum at Casper College, Wyoming, America. The case studies show how the museum has developed programmes with students of different ages to engage with collections in new ways. **Whitman, Viscardi and Reynard** provide a detailed paper on procedures on how to image fragile Blaschka models, providing several step by step guides.

The volume is full of an interesting variety of articles, providing case studies and new ways of working with natural science collections. The Journal is printed in black and white, and there are several articles, particularly by **Granget, Dangeon and Brambilla** and **Whitman, Viscardi and Reynard**, which have a large number of colour illustrations. These can be viewed online (www.natsca.org/jonsc-vol-10) in full colour.

View from the Chair

Isla Gladstone

As this volume of the Journal of Natural Science Collections is published, the invasion of Ukraine is at the forefront of our minds. The International Council for Museums, Network of European Museum Organisations and the UK's Museums Association are collating lists of resources and advice specific to cultural organisations, and NatSCA both support these and extend our thoughts to all colleagues affected.

The impacts of the Covid-19 pandemic also continue to affect our community. NatSCA has been made aware of a number of collection posts at risk over the past year, for which we have provided support through letters or advice. If you would like to get in touch about a collection at risk you can contact us at advocacy@natsca.org.

NatSCA's priority in advocating for natural science collections is in supporting understanding of their scientific and societal relevance - through our platforms, resources and partnerships. This year we have been partners in an important project to scope a UK digital infrastructure for natural science collections, led by the Natural History Museum London. Here we are enabling project communications and highlighting NatSCA's legacy data on UK collections, to support as broad a reach as possible. The project scoping phase ends in March 2022 and we look forward to the overview of UK collections and digital capabilities it will provide. We will also be supporting next steps to secure longer-term funding and infrastructure. NatSCA are also a partner in a new AHRC networking project called 'People and Plants' led by National Museums Scotland, Royal Botanic Gardens Kew and the Powell-Cotton Museum. This one year project which runs to December 2022 will include opportunities for members to attend funded workshops to explore reactivating ethnobotanical collections as material archives of Indigenous ecological knowledge, along with members of the Museum Ethnographers Group. We have also continued to represent natural science collections through mechanisms such as the steering group of the Subject Specialist Network Consortium.

Following a successful digital conference on natural science collections and environmental breakdown in May 2022, NatSCA's conference team is busy preparing for our 2023 conference. We will be partnering with the Society for the Preservation of Natural History Collections (SPNHC) and the Biodiversity Heritage Library for a hybrid in person and digital conference in June in Edinburgh. Recognising the international opportunities this brings but also the significant cost of a larger conference for attendees, we have awarded a substantial number of bursaries to support members to attend. The NatSCA trustees have organised two sessions at the conference – one with a focus on the societal relevance of natural science collections, and one with a series of lightning talks aiming to support sharing and reconnection across our community following two years of working digitally.

New NatSCA trustees elected in 2021, Laura McCoy and Laura Soul, are currently trialling a Lunchtime Chats slot for NatSCA members. These launched in January and occur on the last Thursday of each month. They are intended as an opportunity for the more informal information sharing that we have all missed over the pandemic. We are also hoping to reinvigorate our training programme over the next year, so please do get in touch if you have ideas for this.

NatSCA's blog has remained active throughout the year with some wonderful contributions. These include updates on projects funded through our Bill Pettit Award, such as the conservation of the Bateman ichthyosaur at Sheffield Museums Trust and mounting of the Royal Albert Memorial Museum's River Otter Beaver. We will be scheduling the next round of this Award soon. We also have a fantastic range of articles in this year's journal, which is our second journal publication of the year following our open decolonisation volume published in November.

Finally, thanks to all of our trustees, volunteers, members and users for your valued contributions to NatSCA over the past year. We will share individual thanks and more specific data about our activities in our 2023 AGM annual reports. For now I would like to recognise all of the behind the scenes work that goes into running NatSCA from roles such as our Treasurer, Secretary, Membership Secretary, Conservation and Web leads, as well as those involved in delivering all of the activity outlined above, our volunteers and everyone who contributes expertise or delivers content via our platforms. We have a number of trustee positions opening up at our 2023 AGM. If you are interested in becoming a trustee of NatSCA please do look out for the information we'll be sharing about this, or get in touch directly at chair@natsca.org.

Mineral displays as embodiments of geologic thought and colonial invisibility

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Abstract

Mineral displays embodied how we think about minerals: as symbols of social status, scholarly tools, theological objects, and instruments of education. Mineral displays are also representations of how we *don't* think about minerals: as human products embedded in wider human histories. This paper reviews the historical themes in mineral display, from the cabinets of curiosity of the Renaissance to modern museums, and articulates a major narrative that has been omitted from mineral display traditions: the human processes that bring mineral specimens from the ground to the display case, particularly Western colonialism and labour. Historically, mineral displays have been used to provoke thought about mineral formation and wider Earth processes; here, too, mineral displays can be used to provoke thought about the human processes that created modern Geology.

Keywords: Mineral collections, mineral displays, history of science, history of geology

Introduction

Mineral displays embody how we think about minerals. Starting with Renaissance cabinets of curiosity and continuing to modern natural history museums, minerals have been seen variously as symbols of social and political power (e.g., Wilson, 1994, Vogel, 2015), tools for understanding the Earth (e.g., Laudan, 1987), objects of theological significance (e.g., Guntau, 1996), expressions of nationalistic pride (e.g., Vogel, 2015), and instruments of both formal and public education. Those values have guided how minerals have been collected, organised, and displayed (Kohlstedt and Brinkman, 2004).

However, mineral displays have also revealed how we *don't* think about minerals: as human products entwined with human histories, particularly histories of Western colonialism. In both historical and modern displays, minerals are almost uniformly presented as 'wonders from the underground.' This display choice renders minerals as 'natural' objects that appear free of human contact. In reality, the vast majority of display-worthy mineral specimens have been collected by miners, by the chain of people who eventually brought those specimens into collections, and by the scientists who used those specimens in their work. Those processes did not happen in isolation: they were embedded in local, national, and international histories of land, labour, migration, racism, colonialism, and imperialism. Often, the minerals themselves were the central motivating forces in those histories: what is Western colonialism without gold, silver, diamonds, or copper?

This topic is particularly relevant right now, as museums' many-decades-long decolonising efforts extend into natural history collections (e.g., Das and Lowe, 2018; Gelsthorpe, 2021; Freedman, 2021). While the core of decolonisation must be material reparations (e.g., Tuck and Yang, 2012), dismantling Western colonialism in the sciences also requires understanding and articulating how the two are entwined. The omission of colonial narratives from mineral displays is not accidental; it reflects a corresponding absence within the geological community.

This paper will examine how mineral displays have embodied mineralogic thinking through time – and how shifting perspectives about the significance of human histories could exteriorize in mineral displays in the future. It will do so through the lens of the Bryn Mawr College Mineral Collection: a college collection of around 44,000 mineral specimens, most of which were collected in the mid-1800s to early 1900s.

Mineral displays from the Renaissance to today

Mineral collecting is probably as old as humanity itself (see Wilson, 1994, pp. 13-17, for a summary of pre-Renaissance mineral collecting in Europe); however, modern-style mineral *display* arose in response to the emerging principles of the Renaissance and Scientific Revolution, the rise of the middle class, and the growing body of specimens flowing from colonial sites back to European metropoles (e.g., Impey and MacGregor, 2000). These trends produced the iconic Renaissance 'cabinet of curiosity' or 'wünderkammer,' the start of the modern mineral display lineage. The sections below review themes in mineral displays from the Renaissance to today, in order to illustrate the ways that mineralogic displays have showcased mineralogic thought.

For the purposes of this paper, 'minerals' carry their modern definition: inorganic, naturally-occurring solids with ordered internal crystal lattices that can be represented by a single chemical formula. However, it should be noted that this definition has changed considerably since the 1500s. For many of the collections discussed below, 'mineral' meant anything that was neither animal nor vegetable, and could include rocks, fossils, and even liquids. Portions of the Bryn Mawr 'mineral' collection from the mid-1800s include vials of sand from the Sahara Desert, brines from various inland seas, and even a tube of gas. When the distinction is relevant, it is noted below.

As symbols of social status

In the West, minerals' most common cultural use has been as symbols of social standing: of the owner's wealth, power, taste, or education (e.g., Wilson, 1994, pp. 46-47). This role has yielded distinct display traditions.

Minerals as symbols of wealth and taste are exemplified by the collections of European aristocracy. From the 1500s onward, but especially during the Enlightenment, European aristocrats considered it highly fashionable to engage in – and to be *seen* engaging in – mineral collecting (e.g., Wilson, 1994, Vogel, 2015), and they designed their cabinets accordingly: displays housed large, rare, expensive, or visually stunning specimens in surroundings that were "correspondingly elegant" (Napolitani, 2018). In 1784, France's King Louis XVI (1754-1793) renovated a special *salon d'honneur* at the Hôtel de la Monnaie to house his mineral cabinet: 16 glass-faced mahogany cases "richly adorned with interwoven laurel leaves in lead" (Napolitani, 2018). In 1791, Austrian Empress Maria Theresa (1717-1780) commissioned an entire room in her *Naturalien-Cabinet* to display a "bouquet" of diamonds and other cut gemstones. By the 18th-century, mineral interest among European aristocracy had built into a "mineral craze" (Simon, 2002), making the time period "the zenith of mineral collecting" (Vogel, 2015). Paris and Vienna in particular became major hubs of the mineral trade, and, "by 1776, most of the Austrian nobility collected minerals and every nobleman … had a small cabinet of minerals in his apartment" (Franza *et al.*, 2019).

For the Enlightenment-era rising middle class, too, minerals served as social symbols, not of wealth, but of education. The aristocracy-driven interest in minerals gave rise to a professional mineral trade that allowed middle-class collectors to assemble personal cabinets of more affordable specimens (Fritscher, 2012). At the same time, publications like Michael Bernhard Valentini's popular 1714 *Museum Museorum* drove interest in mineral collecting among the educated middle class. Johann Gottfried Herder (1744–1803) commented on 1780s Weimer's educated, aristocracy-adjacent class: "At that time, the person was nothing, the stone everything… Everybody mineralogized; even the ladies found a higher meaning in the stones and started cabinets for their own" (Hamm, 2001, p. 280). The trend also spread to Europe's colonies, and, by the late 1700s, it was common for wealthy and educated middle-class Americans to establish their own natural history cabinets as well (Kohlstedt and Brinkman, 2004).

As with the aristocracy, the social meanings of these minerals influenced their display: often, minerals (and other natural history specimens) were displayed in the most public part of a home (e.g., Olmi, 1993, p. 239). For example, Fritscher (2012) noted that it was common for mid-1800s German amateur collectors to display their minerals in their sitting rooms instead of locking them away in traditional cabinets. In England, the emerging middle class "displayed natural history collections as emblems of their cultural erudition alongside art galleries, libraries and gardens" (Alberti, 2002, p. 292). There, open displays "served the combined functions of display, entertainment, and improvement" (Guntau, 1996, p. 211).

The goal of impressing visitors gave early natural history cabinets their distinctive display aesthetic: ordered, neat, but simultaneously overflowing with the richness of the collection.

> "An orderly museum was a museum in which the various exhibits were arranged in an aesthetically pleasing manner. It contained no empty spaces, and was therefore capable of filling every visitor with wonder by immediately conveying the idea of great riches and variety. With this aim in view, time-tested and well-known expository models were followed: by hanging objects from the walls and especially the ceilings the naturalists were simply returning to the practice of medieval churches"
>
> (Olmi, 1993, p. 237)

For minerals, this display aesthetic often took the form of small divided shelves or boxes (cubbies), each with its own specimen or set of specimens (e.g., Figure 1). Specimens in these cabinets may or may not be labelled, and their organization was likely to be dictated by aesthetics or "arcane and symbolic arrangements of often mysterious significance" (Wilson, 1994, p. 19), rather than the taxonomies of more scholarly displays (see below).

The importance of the *audience* for social mineral displays can also be seen in a tendency for

Figure 1. Hobbyist mineral displays. A) An 1813 painting of the mineral cabinet of Jacques-Louis de Bournon (1751-1825), by Alexandre Isidore Leroy de Barde (1777-1828), in the collection of the Louvre, Paris. B) Late 19th-century British mineral display box in the Bryn Mawr Lenker Collection (GC-148).

Renaissance and Enlightenment non-scholars to alter their minerals into art. Early mineral collector Ferdinand II, Archduke of Austria (1529 – 1595), commissioned artists to transform mineral specimens into artistic scenes ('handstones'), which could include minerals, sculpted human figures, metals, and wires assembled into landscape scenes (Wilson, 1994, p. 31). The naturally-occurring patterns in Florentine 'ruin marbles' so inspired some artists that they added hand-painted scenes to the 'landscapes' inside the rock or cut them into decorative display panels for mineral cases (e.g. Caillois, 1985, pp. 26-28). Especially for non-scholarly collectors, the line between the artificial and the natural was less interesting than the aesthetics of specimens.

As tools of study

From the 16th to 18th centuries, 'minerals as social indicators' dominated collecting: of the 60 largest 18th century European mineral collections (>4,000 specimens), only ten had been assembled by scholars (Wilson, 1994, pp. 46-47).

The pervasive use of minerals as status indicators pained many scholars, who often expressed "a high degree of intolerance … at the slightest trace of old-fashioned collectionism" (Olmi, 1993, p. 236). Early geologist Luigi Ferdinando Marsili (1658–1730) misogynistically lamented that natural history displays were "more intent upon stunning boys, women and ignorants than upon educating scholars about nature" (Spallanzani, 1984). A century later, Johann Wolfgang von Goethe (1749-1832) "could not contain his rage" when it was suggested that the Jena Museum's minerals be stored in glass cabinets, claiming: "the only advantage of glass was that it allowed for dangling something before the gaping masses" (Hamm, 2001, p. 295). Less dramatically but no less emphatically, mineral collector John Woodward (1665-1728) complained of collectors "perpetually heaping up of Natural Collections, without Design of Building a Structure of Philosophy out of them...." (quoted in Price, 1989, p. 80).

For natural philosophers, this "Design of Building a Structure of Philosophy" was the core purpose of natural history cabinets: to gather all the important pieces of the Universe in one place so that natural order would reveal itself (e.g., Kohlstedt, 2020). Because of this, cabinet mineral displays were both *representations* of how scholars thought about minerals – and active *tools* for thinking about minerals.

As representations, cabinet mineral displays were physical evidence of the thoughts of the scholar who organized them (e.g., Laudan, 1987, p. 21). This can be seen playing out on several levels. On the broadest scale, 16th century cabinets often contained both human-made (*artificialia*) and natural objects (*naturalia*), as scholars still believed the realms of the human and natural were intertwined. Sulfur, for example, was seen in the alchemical-lapidary tradition of the Middle Ages as the material form of Lucifer and imbued with correspondingly destructive energies (Hughes, 2012, p. 44). However, as the Scientific Revolution began to center observations and experimentation, scholars separated *artificialia* and *naturalia* in their cabinets, a physical representation of the intellectual separation that was happening at the same time (e.g., Franza et al., 2019, p. 183). Similarly, on the level of institutional collections, the pattern of displays as representations of thinking can be seen in the treatment of meteorites in the mineral collection of Austria's Imperial and Royal Natural History Cabinet in the late 18th century. As the thinking among natural historians shifted to a consensus that these materials fell from space, so shifted the Cabinet's meteorite displays: in 1806, the curators built an entirely separate room in the public cabinet to display the meteorites, physically separating their presentation from other geologic materials (Koeberl *et al.*, 2018). On the level of the individual scholar, mineral displays as representations of thinking can be seen in French mineralogist Balthazar-Georges Sage's (1740-1824) collection. Sage developed his mineral taxonomy hand-in-hand with his chemical experiments on minerals; as his experiments changed his thinking about minerals, so changed his personal cabinet layout (Napolitani, 2018, p. 246).

Displays were also *tools* for thinking about minerals (e.g., Bennett, 2004, pp. 67-68). An individual mineral must be intentionally *placed* in a display, and, for natural historians, that placement signified the mineral's relationships with surrounding specimens (e.g., Simon, 2002, p. 134). A display could not be assembled until the scholar chose – or *developed* – a system for classifying the minerals. However, unlike other natural history disciplines, mineralogy did not have a single widely-accepted classification system until the late 1800s (Hazen, 1984). Instead, individual scholars were left to make their own mineral classification systems for their cabinets. The minerals in front of a scholar, then, became the tools they used to develop their own hypotheses about mineral structures, relationships, and formation processes.

A single scholar might arrange and rearrange their mineral layouts repeatedly as their thoughts on mineral classifications changed (e.g., Vogel, 2015, p. 311). John Woodward (advocate of "Building a Structure" cited above) published, over the course of his career, a long series of mineral classifications, revisions, and additions that reflected his continual reorganization of his personal mineral collection (Price, 1989, pp. 93-95). This display of minerals was not done to impress viewers: it was an act of knowledge production. This was the central research question of mineralogy from the mid-1500s to the late 1800s: how are minerals to be *classified*?

This focus on mineral taxonomies did not arise in the Renaissance – Aristotle had tackled mineral classifications in the 4th century BCE, Avicenna in the 10th century CE, and Albertus Magnus in the 13th (Laudan, 1987, pp. 23-25) – but for Renaissance mineralogists, mineral taxonomies had a new *methodology*. This new standard had been set in 1556 when Georgius Agricola (1494-1555), the 'Father of Mineralogy,' posthumously published his 12-volume treatise on mineral classifications. In the preface, he famously wrote: "I have omitted all those things which I have not myself seen, or have not read or heard of from persons upon whom I can rely. That which I have neither seen, nor carefully considered after reading or hearing of, I have not written of" (Agricola *et al.*, 1912, pp. xxx-xxxi). Departing from Middle Ages mineralogic wisdom, Agricola held that minerals must be classified by their *observable* physical properties.

This mandate was in line with the emerging principles of the Scientific Revolution – which valued observation and experiment over philosophical musings – but it put mineralogists in a bind. The terrible truth for early mineralogists was that they did not have the tools they needed to classify minerals in an exact fashion; those tools would not emerge until the chemical revolution of the 1800s yielded an understanding of elements (e.g., Dana, 1880; Porter, 1981). Instead, Renaissance and Enlightenment natural philosophers had to classify minerals based on the limited physical properties they could observe: colour, luster, hardness, tenacity, cleavage, fracture, parting, taste, grittiness (upon being chewed), electrical properties, optics, growth habits, geographic occurrence, tendency to grow with or near other minerals. They could also make chemical observations: flammability, dissolvability, reactions to various acids. Within many of these categories, a single mineral species might vary widely: quartz, for example, can be *any* color, nearly any habit, a range of lusters, etc.

The result was a glut of classification schemes: Woodward in 1704, Linnaeus in 1735, Henckel in 1730 and again in 1744, Pott in 1746, Wallerius in 1747, Cronstedt in 1758, Bergman in 1783, Werner in 1789, Phillips in 1816, Werner again in 1817 – to name only the most influential (Laudan, 1987, pp. 23-25; Hazen, 1984, pp. 296-297).

This obsession with taxonomy was reflected in mineral displays in both private and public collections. In 1776, mineralogist Ignaz von Born (1742-1791) organized the Imperial Natural History Cabinet's mineral displays "according to the most recent scientific knowledge [of Linnaeus]" (Klemun, 2004). In the mid-1800s, the newly founded Australian Museum organized its mineral displays by taxonomy (Bennett, 1998). French mineralogist Jean-Baptiste Louis Romé de l'Isle (1736-1790) wrote and re-wrote his mineral taxonomies while assembling cabinet displays for French aristocrats (Guntau, 1996, p. 212). The examples of this are endless: 'minerals by chemical class' is still the dominant mode of display to this day, and can still be seen in internationally-recognized natural history museums like the National Museum in Prague, the Smithsonian's National Museum of Natural History, London's Natural History Museum, and the Museum für Naturkunde in Berlin. It can also be seen in the two large (>10,000 specimen) collections that make up the bulk of Bryn Mawr's mineral collection: the George Vaux Jr. and Theodore D. Rand Collections are both organized by different chemical class systems (the Vaux, for example, classifies the quartz family as Tectosilicates, while the Rand classifies it as an Oxide of Silica).

Because of the variety of classification schemes being published, Enlightenment mineral displays were also tools for scientific debate. When von Born reorganized the Austrian Imperial Cabinet, he did so according to Carl Linnaeus' (1707-1778) mineral classification scheme, which focused entirely on mineral *external form*. At the same time, Berlin mineralogist Dietrich Karsten (1768-1810) organized the Leskean Cabinet according to the competing taxonomy of influential early geologist Abraham Gottlob Werner (1749-1817), a classification scheme based on mineral *chemistry*. Austrian Count Moritz von Fries (1777-1826) organized his cabinet in line with the taxonomy of rising French crystallographer René Just Haüy (1743-1822; Vogel, 2015, pp. 310-312), and Antoine-Laurent de Lavoisier (1743-1794) organized his own according to a chemical tradition started by Axel Fredrik Cronstedt (1722-1765; Beretta, 2005, p. 127). In choosing a taxonomic scheme for a display, an organizer was taking sides in broader scientific debates about the nature of minerals and structure of mineralogy.

Simultaneous to the proliferation of mineral classification schemes was the rise of mathematics as a lens to view the world – and the subsequent rise of crystallography. The observations that mineralogists could make of crystals included their crystallographic forms: the exact angles at which their planes met, their symmetries and axes, and their breaking patterns. The rise of this discipline led, in mineral cabinets, to a particular interest in large, crystallographically perfect specimens – and in broken ones. René Just Haüy (the 'father of modern mineralogy') famously smashed crystals in his personal cabinet as he tried to assemble his understanding of how minerals' internal structures controlled their external forms (Whitlock, 1918). Broken pieces of these crystals were displayed as part of his personal collection, because of their importance in illustrating the fundamentals of crystallography (Bureau and Feininger, 2011, p. 664).

From the mid-1500s onward, the iconic scholarly mineral cabinet was a set of drawers that could be removed to examine and study the specimens inside. Many scholars specially designed these drawers to accommodate their taxonomic visions; Johannes Kentmann (1518-1574)'s inventory of his collection included no illustrations of mineral specimens but a detailed illustration of his display cabinet (Wilson, 1994, p. 25). Goethe's mineral cabinets were capped with glass cases, "a concession to the uninformed curiosity of those who longed for a display of a few lovely samples; the real treasures were inside the cabinets" (Hamm, 2001, p. 283). Portions of Bryn Mawr College's mineral collection still reside in the large wooden drawers that George Vaux Jr. (1863-1927) designed to house his taxonomically-sorted specimens in the late 1800s; each drawer houses specimens by type, and can be removed to study or show the specimens inside.

As objects "charged with theological meaning"

The history of science from the 1500s has been a long process of untangling science and religion. This has been especially true for geology, where, even through the 19th century, geologic formations were often ascribed Biblical causes. These 'physico -theologists' argued, for example, that Noah's Flood was responsible for all manner of geologic phenomena ('diluvialism'), including fossils and all sedimentary rocks (e.g., Huggett, 1989).

As a result, for some mineral collectors (both amateur and scholarly), earth materials were often "charged with theological meaning" (Guntau, 1996, p. 211) and their description and interpretation were less about aesthetics, social status, or taxonomies – and instead about affirming religious convictions (e.g., Håkansson, 2020, pp. 456-459). (Fossils in particular inspired theological speculation, but those are outside the scope of this paper).

This religious framing exhibited in mineral collections as interest in specific types of rocks and minerals seen as having biblical significance. 'Graphic granite,' for example (Figure 2A), are light

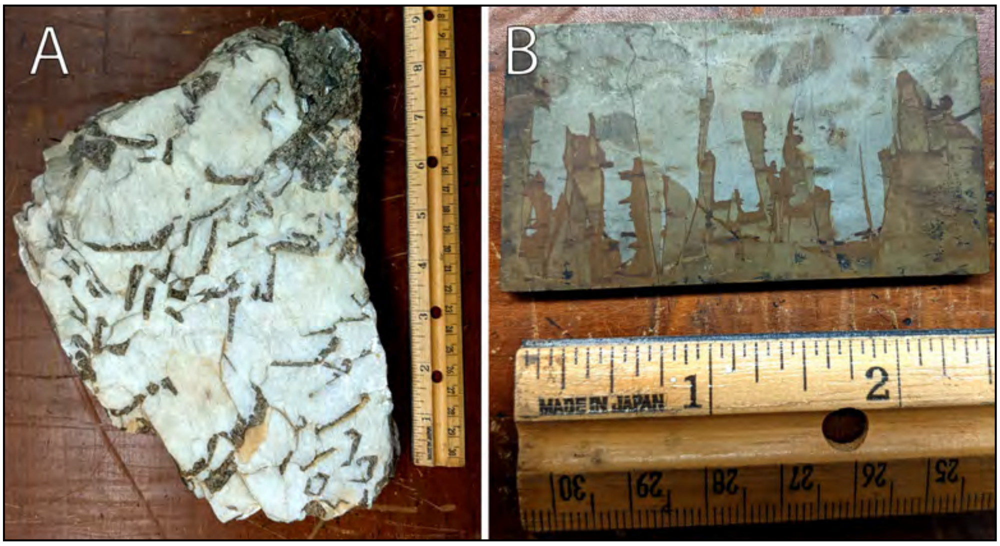

Figure 2. A) Graphic granite: the light-colored material is alkali feldspar, the gray twisting shapes stringers of quartz that chemically separated from the feldspar as it cooled in an underground magma chamber. These twisting stringers were once interpreted as writing, and collected and displayed as religious artifacts. Bryn Mawr Teaching Collection, unnumbered. B) Ruin Marble: a siltstone heterogeneously stained by iron-rich groundwater filtering through fractures. Bryn Mawr Rand Collection, sample 22-6. Like the graphic granite, ruin marbles were sometimes collected and displayed as religious artifacts.

-colored plutonic rocks that underwent mineral exsolution, separating quartz and alkali feldspar into distinctive stringers that look like cuneiform or Hebrew writing, giving them their French name, *Pierre hebraïque*. Some collectors interpreted the graphic texture as the Christian God's attempt to write Hebrew inscriptions into the granite (e.g., Guntau, 1996, p. 218; Davies, 1856, pp. 136-139). Similarly, rare siltstones from near Florence, Italy, when cut, show on their surfaces networks of cracks and stains that look like ruined landscapes and burning cities. These *Ruinenmarmor* (also called *Pietra Paesina*, *Pierres-aux-masures*, Ruin Marbles, or Landscape Marbles) are caused by water-transported color-causing elements (e.g., iron or manganese) staining the rock around the fractures. The apparent ruined cities trapped in these specimens inspired centuries of theological speculation (Caillois, 1985, pp. 15-36). 'Figured' stones, or stones shaped by weathering into shapes suggestive of human form, were also popular collecting items (Coglitore, 2004, p. 49).

As formal teaching tools

Hand-in-hand with the rise of natural philosophy came the teaching of natural philosophy – for this purpose, too, mineral displays were central. Up to the mid-20th century, science pedagogy was based heavily on developing students' practical skills, often relying on the study of physical specimens. Examples of these teaching displays are abundant. Rutgers University's natural history cabinet grew to occupy an entire building by the mid-1800s, and its mineral displays were used as teaching tools in its geology and natural history courses (Neitzke-Adamo *et al.*, 2018). Bryn Mawr College's Geology Department had in its mineralogy lab, up until 2017, a series of glass cases displaying representative minerals by type, classification, and physical properties (Figure 3A). To this day, the Smithsonian's National Museum of Natural History includes a "Study Gallery" of minerals by chemical class, as does the mineral gallery at the Natural History Museum, London.

Physical specimens are still central to geologic pedagogy today (e.g., Chatterjee and Hannan, 2015), but not the physically exceptional specimens of the mineral cabinet. Today's Bryn Mawr mineralogy students learn to identify minerals as they are usually seen in the field: altered, small, and imperfect. As practicing geologists, students will almost certainly never encounter inches-long azurite crystals in the field; they'll more likely encounter smashed-up bits of alkali feldspar. So, in class, they practice with smashed-up bits of alkali feldspar. The inches-long azurite crystals are stunning – but no longer *pedagogically* central to training geologists. Indeed, our mineralogy course goals have expanded to include emphasizing student understanding of the social roles of minerals, the wider geologic context under which minerals form, and the ways that minerals can be used to learn about geologic processes. These later goals do not even require physical specimens. The old teaching display cases have been disassembled and the minerals inside repurposed for public education display.

Instructing students in mineral taxonomies reinforced the dominant mode of mineral display as 'by class;' however, it also introduced a new

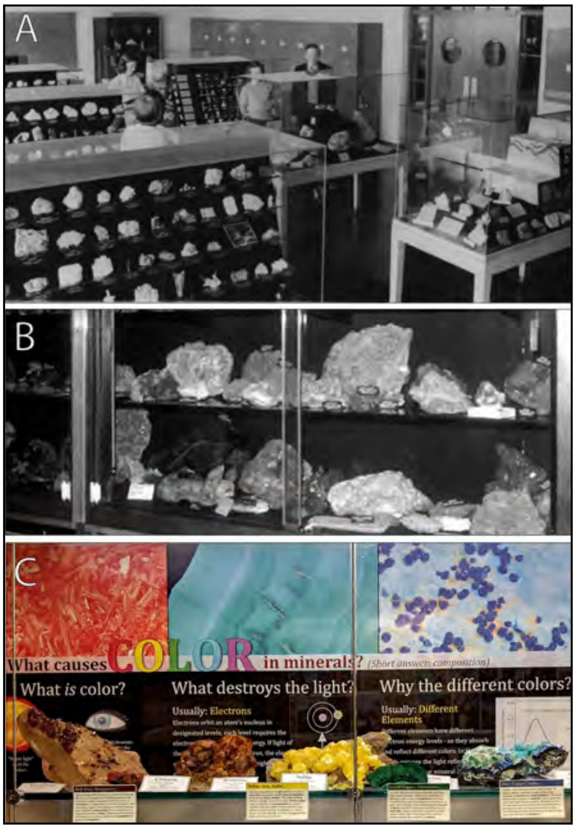

Figure 3. Bryn Mawr mineral displays as formal pedagogical tools. A) Minerals displayed by chemical class in glass cases in the Mineralogy teaching lab at Bryn Mawr. Undated, but likely taken around 1940, when the glass cases were first assembled. These cases were used to teach mineralogy from about 1940 to approximately 2000. They were disassembled in 2017 as part of the Park Science Center remodeling. Image from Bryn Mawr College Special Collections, image ID PA_00511. B) Minerals displayed in Bryn Mawr's Park Science Center educational exhibits for the general public, prior to the 2019 remodel. The labeling is minimal, and there is hardly any explanatory material accompanying the specimens; nevertheless, the specimens succeeded in inspiring a sense of wonder in generations of visitors. C) A 2019 display on the causes of color in minerals in the Bryn Mawr Park Science Center.

form of mineral display: by locality. This mode of display ('suite collections') was popular in mining districts, arising from the need to teach miners about co-occurrences of minerals. It was important that miners knew that, for example, galena (the chief ore of lead) most often occurs in proximity to sphalerite and calcite, not mica and garnet.

As mining operations expanded in the wake of the Industrial Revolution, so did the need to educate miners about minerals. For example, an 1885 report to the Australian Museum advocated for remodeling their current mineral display (which had been based on mineral classifications), and turning them instead into displays of mineral co-occurrences so that miners arriving for the new Australian mineral rushes might "at a glance, understand something of the science of mining" (Bennett, 1998). (The idea that mineral displays could convey important information "at a glance" was controversial. Goethe, for example, thought it "sheer madness" that an uninformed person could glean useful information about minerals just by looking at them; Hamm, 2001, p. 295). Similarly, in 1888 in South Africa, geologist William Guybon Atherstone (1814–1898) advocated for the founding of a national museum specifically to educate students in the "mineral and metallic discoveries [that] are rapidly assuming gigantic propositions" in the colony (quoted in Mackenzie, 2009, p. 114). Prussia used its Royal Mineral Cabinet to train mining engineers, and intentionally organized the collection and its displays geographically around major mineralogic deposits both in and outside of Prussia (Vogel, 2015, p. 313).

The expansion of economic mineralogy in the wake of the Industrial Revolution influenced two other shifts in mineral collection and display: displays as nationalistic marketing tools, and displays as tools of informal public education.

As "patriotic visions"

For governments – Imperial, Royal, and, eventually, democratic – minerals were not just symbols of wealth, but of power: power over nature, but also over *territory* and *populace* (e.g., Vogel, 2015; Rosenberg and Clary, 2018). For example, Napoleon summoned mineralogic specimens from lands occupied by French forces to be housed in the *Musée d'histoire naturelle* (Vogel, 2015, p. 306). The move symbolized his authority over the newly occupied territories – but also over the French populace: the *Musée d'histoire naturelle* had begun as the royal cabinet, had been transformed into the national museum during the French Revolution, and was now under his control. Similarly, in the newly-formed United States, Thomas Jefferson donated the minerals that had been brought back by the Lewis and Clark Expedition to Peale's Museum of Natural History in Philadelphia: the minerals displayed as part of U.S. natural history reinforced that those lands were now part of the U.S. (Conn, 1998, p. 34).

In this context, Western governments starting in the late 18th century began to commission mineralogic surveys of their home countries and occupied territories – and to house the resulting specimens in state cabinets and, increasingly, museums. In 1836, for example, the New York State legislature launched a program to document the mineral resources of New York State. The geologists they hired began by sending specimens back to the State Library, which was quickly overwhelmed. Next, they established the State Cabinet as a repository, but it too outgrew its space and budget within a few years. Finally, in 1870, the State Cabinet was reorganized into the New York State Museum of Natural History (Fakundiny, 1987).

As the scale of geologic research increased, so did geologists' reliance on museums as keepers of specimens. Britain established the world's first national Geological Survey in 1835, under Henry De la Beche (1796-1855) – who immediately also established the Museum of Economic Geology as a repository for the survey's specimens (Clary, 2020). Like the New York cabinet, this survey outgrew its space, and was morphed into the Museum of Practical Geology, then the Geological Museum (Knell, 2000, 2007). For a science so dependent on specimen analysis, these large-scale repositories were central; William Smith – the 'Father of English Geology' – saw geology as permanently "wedded to the concept of the museum" (Knell, 2000, p. 79).

One side effect of this permanent wedding of specimen repositories to government institutions was the expansion of mineral displays as tools for educating the public.

As a means of public education

Natural history cabinets as a means of public education extend as far back as the cabinets themselves. Francesco I de Medici (1541–1587) transformed his private room of rarities into the Uffizi Gallery, open to the public (Conticelli, 2007), and Ulisse Aldrovandi (1522 – 1605) opened his famous private museum to the public in the late 1500s. In 1638, Oxford University opened to the public its Ashmolean Museum of natural history specimens (Lipps, 2018). Maria Theresa threw open the doors of the Imperial Natural History Cabinet as soon as her husband died in 1765:

> In contrast to [her husband] Francis I, who considered collecting a private activity, Maria Teresa was a fervent supporter of the educational value of scientific exhibitions. She firmly believed that opening the imperial mineralogical collection to the public would allow citizens not only to deepen their scientific knowledge, but also to learn the economic value of minerals, thus stimulating new studies and discoveries
>
> (Franza *et al.*, 2019)

Similarly, in the newly-founded United States, Charles Willson Peale (1741-1827) transformed his private natural history cabinet into a public museum in a series of spaces in Philadelphia. Peale considered educating the public about natural history a part of his civic duty: "Natural History is not only interesting to the individual, it ought to become a National Concern since it is a National Good" (Kohlstedt and Brinkman, 2004).

The insistence on museums as institutions of public good via public education was emphasised and re-emphasised from the 1700s onward, but had a major expansion in the last two decades of the 1800s (Bennett, 1998, p. 29). In Britain, Queen Victoria encouraged her citizens to visit museums and even to start their own collections in their homes: "Museum culture was for the people's own good: possession promised self-possession" (Black, 2000, p. 32). If all social problems stemmed from the lack of education and culture of the working class, then perhaps exposing them to culture was the solution.

In terms of display, this resulted in a call for better labeling and more accessible design. For example, the British Association for the Advancement of Science (BAAS) produced a report in the late 1880s, calling on provincial museums to label all objects so the visitors might benefit: "A museum without labels is like an index torn out of a book; it may be amusing, but it teaches very little" (BAAS, 1887, p. 127). Similarly, in the 1890s, geologist and curator of the American Museum of Natural History Louis Pope Gratacap (1851-1917) wrote: "the careful luminous exhibition and exposition of its collections, so that the public may fully understand them, and learn their lessons, is the chief purpose of the Museum" (quoted in Bennett, 1998, p. 29).

This framing of museums as instruments of public education expanded over the course of the 20th century (e.g., Rader and Cain, 2014), and, although many mineral displays remain in the traditional 'by class' or 'by locality' formats, the emphasis on public education has produced several new themes in mineral exhibits. These remain the dominant themes to this day, and include:

"Marvel!"

> "Marvel at nearly 400 dazzling and dramatic specimens from the Academy's geology collection—from iconic gems to newly-displayed natural wonders"
>
> (California Academy of Science, CAS, n.d.)

Today, one of the most common goals of mineral displays is to incite wonder and curiosity in the viewer by displaying the biggest, brightest, strangest minerals. The Smithsonian's National Museum of Natural History (NMNH) has an entire wall dedicated to a single mass of quartz crystals from Arkansas. The Carnegie Museum of Natural History (CaMNH) mineral display "invites you to appreciate the wild variety and beauty of minerals … that come in a large range of striking colors, fascinating forms, and dramatic shapes" (CMNH n.d.). The Denver Museum of Natural History (DMNH) invites visitors to "be dazzled by the largest known pocket of aquamarine ever discovered" (DMNH n.d.). Examples of this type of display are endless. From a scientific perspective, they are more boring than literal dirt, but they are not there to teach about cutting-edge science; they are there to incite wonder.

Inciting wonder is not necessarily an 'unscientific' goal. Modern science requires curious questioners. Rosenberg and Clary (2018, p. 2) note that curiosity is a necessary prerequisite for science as we know it, but it has not been universally appreciated as a virtue:

> Long before the Scientific Revolution, curiosity was viewed in Western civilization with suspicion. During antiquity, in Greece, curiosity was regarded as a trait of busybodies and, later in Rome, as an expression of dangerous or useless knowledge. In the Middle Ages, curiosity was deemed a vice: It was a sin to be curious! Even during the Scientific Revolution, Francis Bacon and Galileo had their doubts about its value … Thus, the expression of curiosity has a history and cultural context that requires nurturing because it is vital to science literacy.

Museum displays that seek to inspire curiosity do so with giant, colorful crystals – but also with sheer numbers. The CaMNH, for example, has a display of dozens of cut colored sapphires that, alone, would have been beautiful, but massed together are visually arresting. Lipps (2007) articulates the value of these kinds of wonder displays in natural history collections more generally:

> I love the parade of stuffed animals appearing to march in some orderly manner through the center of the place and the whale skeletons hanging above visitors, again with limited labeling. Elsewhere the exhibits remain outstanding but the explanations get more detailed and more complex. The kids, who stand in amazement along the parade or silently gaze upwards to see the whale, run right by these exhibits in the quest for items that excite them more ... [Museums] have become "educational" centers with elaborate explanations of evolution, geologic time, paleoenvironments, plate tectonics, etc, etc. Everything is well explained, leaving nothing to the imagination. They are very educational, and I hate it.

Minerals are powerful instruments for provoking awe. Anecdotal accounts from generations of Bryn Mawr alumni repeat again and again that the mineral displays of Park Science Center were their favorite parts of campus, even in days when the minerals were barely labeled and their presentations were perhaps more *piled together* than *displayed* (Figure 3B).

Immediately answering questions

Another common display tactic for minerals is to immediately answer the questions that are likely popping up in viewers' minds; like: "what causes all those colors?" or "how do they grow in those shapes?" This tactic is almost the opposite of the "Marvel!" display: it offers an object to provoke questions – then immediately answers them. For this, too, examples are abundant: the Smithsonian's NMNH includes mineral displays dedicated to how different shapes of minerals form, and Bryn Mawr's 2019 mineral displays include cases on the cause of color in minerals and the shapes they take as they form (Figure 3C).

"Minerals and you"

Another mineral display tactic in service of public education is to connect minerals with our everyday lives. The list of these connections goes on and on: salt in our food, apatite in our bones, gypsum in our walls, copper in our wires, dozens of rare minerals in our technologies, minerals in the pigments of our favorite paintings. The Museum für Naturkunde, Berlin, focuses several displays on minerals in technology. CaMNH mineral displays invites viewers to "learn about minerals that make up everything from table salt to diamond rings" (CaMNH n.d.). CAS similarly offers: "Learn about minerals in your everyday life, present in products from smartphones to toothpaste" (CAS, n.d.). Bryn Mawr's 2019 displays include the paint pigments of van Gogh's *Starry Night* and the minerals used to make cell phones.

Fundamentals of Earth processes

Another modern mineral display tactic is to link minerals to the fundamentals of Earth processes: how do geologists use minerals to understand how geology works? Displays at the Smithsonian's NMNH link minerals to growth mechanisms like evaporation. CAS features a "Gems and Minerals Unearthed" exhibit focusing on minerals' roles in geologic processes. The San Diego Natural History Museum (SDNHM) invites viewers to "discover how the same Earth processes that build landscapes produce dazzling gemstones" (SDNHM n.d.), and Bryn Mawr's 2019 displays illustrate the geologic history of the Philadelphia region using local minerals and rocks.

Illustrating the process of science

Mineral displays are more likely to attempt to illustrate fundamental principles of geology than to dive into modern mineralogic research, and for a good reason: modern research is usually incredibly removed from the lived experiences of the average person. Questions like, "How does the bond angle of this mineral change?" are fairly alienating for non-experts. As science has become more specialized, discussion of science with the general public has become less about current research and more about fundamentals.

Still, there are some examples of mineral displays as exhibits of current research: the Natural History Museum of Vienna renovated their mineral displays in 2017 to illustrate the concept of 'mineral evolution:' how the types of minerals formed on Earth have changed over its history in relation to changes in the biosphere (Koeberl *et al.*, 2018). The Cleveland Museums of Natural History (ClMNH) features a fishbowl-style display of the process of research: "volunteers sorting and cataloging specimens; and student researchers cutting, grinding, and analyzing the mineralogy of rock specimens with an Ultraphot polarizing microscope" (ClMNH, n.d.). Bryn Mawr's 2019 displays include minerals as tools to understand past water on Mars, a rare field where minerals are both still scientifically exciting and accessible to the general public.

Old themes, modern exhibits

Modern mineral exhibits also incorporate older themes explored above. 'Minerals by chemical class' and 'minerals by locality' are still the dominant modes of display for both small- and large-scale museums. Additionally, museums still use minerals as social symbols, not of *personal* wealth and power, but of their *institutional* distinctiveness. The Smithsonian NMHN toutes the Hope Diamond. The Museum National d'Histoire Naturelle (MNHN), Paris, features "minerals and crystals that belonged to the great scientists of the 18th and 19th centuries, like Romé de l'Isle, Haüy, Des Cloizeaux or Lacroix" (MNHN, n.d.). The Natural History Museum of Los Angeles County (NHMLAC) describes theirs as "one of the world's most valuable collections of gems and minerals," and invites visitors to "marvel at over 300 pounds of gold—including the 'Mojave Nugget,' the largest known nugget of California gold" (NHMLAC, n.d.). The old show pieces of European aristocracy are still central specimens in modern museums: Paris's Musée de Minéralogie, for example, still exhibits gems from the French Crown Jewels.

Mineral displays and colonial invisibility

> *"...certain kinds of narratives, images and objects become canonised and accepted as the most truthful or appropriate ways of organising the world."*
>
> (Mason and Sayner, 2019)

In almost 500 years of mineral display, minerals have been indicators of social status, objects of study, theological specimens, pedagogical tools, nationalistic marketing, and instruments of public education. Often absent from these display traditions are the broader human processes that delivered these specimens from the ground to the display cabinet.

This invisibility is not limited to minerals: Western museums and collections are in the midst of a many-decades-long reckoning with the human histories of their objects, particularly their relationships with Western colonialism, imperialism, and the racism that has infused and enabled those processes (e.g., Simpson, 1996; Barringer and Flynn, 1998; Scott, 2007; Mackenzie, 2009; Edwards and Mead, 2013; Das and Lowe, 2018). Most of this discussion has centered on cultural objects, though Mackenzie (2009) and Das and Lowe (2018) illustrate how natural history collections in particular retain colonial narratives and whitewash object acquisition histories.

Mineral collecting is deeply entwined with histories of social violence. For colonialism in particular, mineral deposits have been some of its greatest motivators and funders: colonising forces could sell mineral wealth to pay for additional colonising efforts. Silver from Potosí (in modern Bolivia) upended the global economy starting in the mid-1500s (e.g., Brown, 2016); Kimberley diamonds and gold fueled South Africa's colonization (e.g., Worger, 1987); lead and zinc from Broken Hill, Australia, poured directly into the smelters of Europe's expanding factories (e.g., Forsyth, 2018); rubies propelled the British in Myanmar (Turrell, 1988), gold the U.S. in the Black Hills, silver the Spanish at Zacatecas, and copper the Spanish throughout Chile. It is not an exaggeration to say that the entire modern Western world is built on minerals mined from colonised land.

The same mines that motivated, funded, and fueled Western colonialism, imperialism, and industrialisation also yielded the museum-quality mineral specimens now displayed throughout the West. Potosí, Kimberley, Broken HIll, Myanmar rubies, Black Hills gold, Zacatecas silver, and Chilean copper specimens can be found throughout the Smithsonian NMNH, London's Natural History Museum, the American Museum of Natural History – and the Bryn Mawr College mineral collection. These specimens are both products of and symbols of the colonial processes that delivered them from the ground to the museum, but those histories are rarely (if ever) addressed in mineral display until recently (Gelsthorpe 2021).

"Museal silence"

The "museal silence" around the social violences of mineral acquisition probably has several causes; the most obvious of these is "museums thinking they have nothing to say" (Mason and Saynor, 2019). The mineral display traditions outlined above mask the human narratives that underlie mineral acquisition. In particular, mineral displays' 500-year obsession with taxonomies is so ingrained that both large internationally-renowned and the smaller local natural history museums often default to it, despite the fact that mineral taxonomy has not been an interesting scientific question for almost 200 years.

More recent mineral display tactics that try to link minerals to the human realm do so by linking minerals to the *viewer*, not the mineral's own human past; CAS invites visitors to "Learn about minerals in your … toothpaste "(CAS, n.d.), but not "*How* do these get into your toothpaste?" For example, a large percentage of toothpaste's magnesite abrasives are mined by a Chinese corporation in Kamaduo, Tibet. The mine poisons local waterways and grazing lands used by fishermen and herders (Denyer, 2006), and the extreme altitude makes it a profoundly hazardous place for workers, even by mining standards (e.g., Wong, 2013). The human processes that bring minerals from Tibet to toothpaste are compelling, important - and hidden. This omission is partly because these stories are difficult to find -- but also, difficult for the public to hear (e.g., Gelsthorpe, 2021).

Mineralogical silences also likely stem from gaps in the historical record -- and whose voices are considered important (e.g., Mason and Saynor, 2019). The voices most likely to be recorded in the process of mineral collection are those of the (almost always) white Western male mineral collectors sent to the mine to acquire specimens, often on collecting trips sponsored by museums (e.g., Wilson, 1994, pp. 136-150). The voices of the miners themselves or the communities affected by the mines – particularly in colonised countries – are substantially less likely to have been recorded, and might only be able to be pieced together in aggregate from disparate historical sources or oral histories of modern descendents.

For some museums with more modern collections, external pressure could also inhibit telling human histories (e.g., Mason and Saynor, 2019). The University of Arizona's Mineral Museum, for example, highlights spectacular copper minerals from the Bisbee mines of southern Arizona. In addition to Bisbee's long colonial histories, these mines are the site of one of the most infamous labor rights violations in U.S. history: in 1917, the Phelps Dodge Corporation kidnapped about 1,300 striking miners and abandoned them in the desert 200 miles away (e.g., Foner, 1987). As Phelps Dodge is now a donor to the UofA mineral museum, it is unlikely that the UofA mineral displays will engage with the labor histories under which many of their specimens were produced.

'Re-reading minerals as human products

Failing to address histories of violence surrounding mineral acquisition continues rendering those parts of our histories invisible (e.g., Edwards and Mead, 2013; Fletcher, 2012, p. 423). This is particularly damaging right now, as our modern world is more reliant than ever on minerals. The historical conditions that yielded individual minerals in our collections also yielded the modern mining world, which delivers mineral products to Western consumers as everything from phones to earrings – all while masking the human realities of their production. Using displays to examine and illuminate the human histories of mineral specimens in our collections makes visible the fact that minerals are human products – in the past, and in the present.

One way of engaging with mineral colonial histories is through the kind of "object biographies" described by Alberti (2005). Such biographies examine museum objects through the lenses of the people they have encountered on their way to the collection, illuminating both the immediate human realities of mineral production and the larger social mechanisms that produce those realities.

For example, the Bryn Mawr College mineral collection houses several world-class specimens of the copper carbonate mineral azurite from the Tsumeb Mine of what is now northeastern Namibia. Over the course of their histories within the collection, these azurites have embodied many of the themes that have shaped mineral displays: they have been social symbols of the collector (George Vaux Jr.), tools of study (their crystallographies are exceptional), and instruments of both formal and public education. In Bryn Mawr displays, they have been quintessential 'Marvel!' objects, with shockingly blue colors and eye-catching crystal forms. They have also been tools for immediately answering questions: the blue colour is a textbook example of electron transfer as a cause of mineral color. They have been displayed according to a range of themes, including 'Minerals and You' (azurites were ground for paint pigments throughout history), 'minerals by locality' (azurites are the most famous of the Tsumeb specimens), and 'minerals as clues to fundamental Earth processes' (crystal growth). In the course of their 'lives' within the collection, the Tsumeb azurites have embodied many of the historical themes of mineral displays.

The Tsumeb azurite crystals, though, had 'lives' before they entered our collection; and those were defined by first German and then South African occupation of what is now Namibia. The human biographies of Tsumeb azurites begin with the precolonial Namibian communities who spent centuries mining, smelting, and trading Tsumeb copper, and the early colonial struggle between Germany, Britain, the independent Boer republic of Upingtonia, the Kingdom of Ondonga, and the local Hai||om and Herero communities over control of the copper mines (Hearth, 2021). German control of the copper deposits was one of the issues that provoked the Herero War that attempted to end German occupation, and Germany's subsequent 1904 Herero Genocide. The azurites now housed at Bryn Mawr were produced by Ndongan and Herero miners in 1929, amid a backdrop of extensive colonial changes in Namibian migration, labour, and recruitment practices, many of which were directly caused by the Tsumeb mine (e.g., Cooper, 1999).

Conclusions

This work has shown that mineralogic displays have always embodied mineralogic thinking -- and that they can also be drivers. As Geology reckons with its colonial histories, thoughtful display of specimens with deep colonial histories can both embody and provoke that process (e.g., Das and Lowe, 2018; Gelsthorpe, 2021). For a small-scale institution like Bryn Mawr College, this starts with examining the origins of the collection and doing the time-intensive work of identifying the human processes that brought specimens into this institution. This process can be reflected in displays as it is carried out: with updated labeling, displays centered on areas of ongoing research, and student involvement in the form of classes and volunteer student assistants. Currently, the focus of our collection's colonial research are the Tsumeb azurites: articulating the colonial histories that brought them from the ground (Hearth, 2021), and translating those into public displays in our science center.

New pedagogical goals for mineralogy meant the old teaching display cases could be disassembled, the minerals inside repurposed for public education display. But our goals for public education and museum displays should be similarly revised to include the human processes that produced them. Both historically and today, minerals have not been mute objects, but rather "things that talk" (e.g., Daston, 2004), or, as Claude Levi-Strauss put it: objects that are "good to think with." Shifting the conversation with these specimens to include the human processes that produced them must be a part of the 're-reading' of both natural history collection and the history of Geology more generally.

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Underestimated: unexpected. Natural history collections in regional museums. A case study based on the collections of molluscan shells in the Doncaster City Museum & Art Gallery

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Abstract

This paper analyses the molluscan collections in the Doncaster Museum and Art Gallery. Collections relevant to historic regional biodiversity distributions are present in the Hargreaves and Morehouse collections. The Morehouse collection illustrates the inter connectedness of collectors and collections during the late 19th and early 20th centuries. Unrecorded transfers of collections between museums especially that of Bean material from Scarborough Museum to Doncaster were uncovered. The Bean material contains specimens of historic and possible type significance. This paper concludes that smaller regional collections contribute valuable additions to the UK and global biodiversity collection resource and warrant further research and enhanced access.

Keywords: Conchology, historic collections, collection significance, social networks, Doncaster Museum

Introduction

The aim of this paper is to illustrate that perceived, unremarkable collections held in regional UK museums form a part of an important network of collection resources. While in themselves such collections do not rank highly in terms of taxonomic significance, they do hold specimens of value and taken together with similar collections held in similar museums constitute a national resource that should not be underestimated. These along with their counterparts in the larger national and university museums form a much larger national, and ultimately international, resource. In addition to any taxonomic value, such collections often hold a local value in reflecting past biodiversity. Finally, such collections may also have a social history dimension reflected in the collectors and their network of sources.

In recent years various collection-based projects have unveiled hidden value in collections held in museums not recognised for their holdings of molluscan shells. The web site (https://gbmolluscatypes.ac.uk) listing the location of type specimens of Mollusca in Great Britain and Northern Ireland is the most recent product of such investigations (Ablett *et al*., 2019). Wider ranging, molluscan collection, reviews have been carried out at The Royal Albert Memorial Museum, Exeter (Oliver, Morgenroth, and Salvador 2017; Oliver and Morgenroth 2018: Morgenroth, Oliver, and Breure 2018); at Tenby Museum and Art Gallery (Oliver *et al*., 2020) and at Hergest Croft (Oliver and Pegg, 2021). In most of these surveys the focus was on specimens of historic, taxonomic value related to specific authors.

In this paper the entire collection of molluscan shells in the Doncaster City Museum & Art Gallery is reviewed. Such collection surveys are not new, and others were done in relation to the Effective Collections project funded by the Esmée Fairbairn Foundation, including one that I carried out in 2012 for the Doncaster Museum and Art Gallery. Such reviews were made to assist managerial decisions and were not designed to be published. Two small papers resulted from this review (Oliver, 2012; Oliver, 2015) but the bulk of the results outlining the history of the collections, their wider significance and the contributions of one of the few female collectors, Elsie Morehouse, remained unpublished.

Documentation

As with many smaller museums the level of documentation is variable but here the work of a former curator, Dr Peter Skidmore (1936–2009) (Hower, Limbert, and Buckland, 2010) has been critical in understanding the provenances of the natural history collections. For the Mollusca he created a hand-written card index detailing the various collections held in Doncaster. Doncaster Museum embarked on acquiring collections from other museums either whole or in part and this appears to be the actions of the Director E.F. Gilmour between 1951–1967. This practice has resulted in the unexpected presence of material exemplified by part of the Bean Collection, being acquired from the Scarborough Museum where one would expect to find it in its entirety.

Collections from other museums include those from Worksop, Chelmsford, Carlisle and Kilmarnock; none of which carry registration numbers but are simply marked, for example, 'ex Carlisle mus'. Material from Selby Museum is accessioned under 1965.739 and that from Wakefield Museum under 1981.176. None of these collections carry accession numbers from their original museums. The major collections acquired from individuals are J.A. Hargreaves (1920, No 20.29) and Elsie Morehouse (1974, 269.74), with minor collections from J.A. Patterson (1965, 1965.837); W. Parkin (1975, 1975.258) and E. E. Gregory (1861–1937) by M. C. Barlow (1976, 1976.540.10).

In this review the focus is on the Hargreaves and Morehouse collections followed by summaries of the collections acquired from other museums.

Collections from individuals

John Ashworth Hargreaves (1856–1929)

John Ashworth Hargreaves was a founder member of the Scarborough Field Naturalists Society, a member of the Conchological Society of Great Britain and Ireland, Yorkshire Conchological Society, Yorkshire Naturalists Union and trustee of the Scarborough Philosophical and Archaeological Society (Gyngell, 1929). He published two significant papers on the land and freshwater Mollusca of Scarborough (Hargreaves, 1909) and the marine Mollusca of Yorkshire and the Dogger Bank (Hargreaves, 1910). The accession register described his collection as an almost complete collection of British land, freshwater and marine shells, some hundreds of specimen lots in all. It was accepted in 1920 and the sum of £10 was paid.

The collection carries Hargreaves own hand-written labels but there is evidence of secondary collectors, the most frequent being Walter Gyngell [1857–1933] who along with Hargreaves set up the Scarborough Field Naturalists' Society in 1888 (Clarke and Wallis, 1933).

The label in Figure 1 shows Hargreaves bold and

Figure 1. Label in the handwriting of J. A. Hargreaves (top two lines) and W. Gyngell (lower two lines). © Doncaster Museum and Art Gallery.

legible writing above the scrawling hand of Gyngell below. Both men were active members of the Conchological Society of Great Britain and Ireland and frequently submitted records and exhibits at their meetings.

The collection of land snails is particularly rich in named varieties of British species and their distribution, primarily in Yorkshire. Hargreaves' collection of marine shells contains rarities poorly represented even in national collections. Examples are the large wood-boring bivalve *Xylophaga praestans* Smith, 1903. Only two records are present on the NBN Atlas and although the Doncaster record is not listed it may have been part of the type series collected from the 'Northumberland coast'. Despite the labels indicating that the shells are from Hargreaves collection, the label and accession number are for the Morehouse collection. Such mixing of collections is not unusual here and probably a situation not uncommon in many museums.

Another interesting lot (Figure 2) that has no accession number but is probably ex Hargreaves, as the shells were collected in 1900, consists of six examples of what is now known as *Idas simpsoni* Marshall, 1900.

The data associated with this lot is that of the type lot and probably came from J. J. Simpson who found these attached to sunken whale bones.

Figure 2. The rare bivalve Idas simpsoni *probably from the type lot collected by JJ Simpson. © Doncaster Museum and Art Gallery.*

While these shells came to Hargreaves, they may not have been part of the original Hargreaves donation to the museum but found their way to Elsie Morehouse. Skidmore in manuscript notes, quoting Elsie Morehouse, stated that only shells from Yorkshire comprised the Hargreaves donation and that the remainder went to a Mr North of Huddersfield and these were later acquired by Elsie Morehouse.

This last lot indicates that Hargreaves exchanged shells with other well-known collectors, most of these in the north of England. He was very friendly with Fred Taylor [1871–1949] (Jackson, 1949) and the labels show exchanges with Robert Standen [1854–1925] (Jackson, 1925) and John E Cooper [1864–1952] (Salisbury, 1953).

Examples of species now on the threatened and endangered list of species in the UK (Seddon, Killeen, and Fowles, 2014) are also represented. The freshwater Glutinous snail, *Myxas glutinosa* (Müller, 1774) was once widespread in England and Wales but has now declined to the extent that it is known to be living at a single site in Wales (Willing *et al.*, 2014). The Hargreaves shells are labelled 'Cleethorpes' and undoubtedly represent an extinct population. *Segmentina nitida* (Müller, 1774) although not endangered is listed as vulnerable (Seddon, Killeen, and Fowles, 2014) and is represented in the collection from Askham Bog, now a nature reserve not far from York.

Elsie M Morehouse (1884-1969)

Elsie M. Morehouse (McMillan, 1969) was undoubtedly an enthusiastic amateur naturalist and collector of shells (Figure 3). She was a member of many societies: Doncaster Naturalists' Society, Yorkshire Naturalists' Union, Yorkshire Conchological Society, the Conchological Society of Great Britain and Ireland and the Malacological Society of London.

Her forte was the recording of land and freshwater molluscs, mostly in Yorkshire but similar trips were made farther afield. This is her major contribution to natural history and her efforts are widely represented in her collection. She published only a few notes in the Journal of Conchology and the Yorkshire Naturalists Union Bulletin. However, she gave numerous talks and lectures to local societies and she frequently exhibited parts of her collection at the Conchological Society meetings in London.

Beginnings of her serious collecting can be traced to the mid or late 1920s when her daughter Kathleen is recorded to have said that her mother

Figure 3. Elsie May Morehouse, photograph in the Doncaster Museum. © Doncaster Museum and Art Gallery.

acquired the collection of John Collier North (information deficient) of Huddersfield and that the foreign shells from the Hargreaves collection were said to be in the North collection (archival notes by Skidmore associated with his card index). Evidence in the Morehouse collection is present in the form of many notations on the reverse of the glass topped boxes e.g. "J. A. Hargreaves Coll, 1932". This indeed suggests that she acquired the North collection and her archive includes one letter from J.C. North. This connection would be unremarkable except for the fact that J.C. North was known to possess the remnants of the Hanley collection before his donation of that collection to Huddersfield Museum in 1932. This was subsequently transferred to Leeds Museum in 1957. The 1932 date does suggest that North disposed of his collections around that time, coinciding with the expansion of Morehouse's collection. Sylvanus Hanley (1819-1888) (Norris and Dance, 2002) was an eminent conchologist who wrote many books and whose collection contained many types. One cannot exclude the possibility that some of the Hanley material came to Morehouse and, in particular, one should look carefully at the North American unionid mussels in her collection. During my review I did not recognise such shells but among the seven drawers of unionids there may be some. It is not known exactly which shells came from North as there are no labels linking him to individual lots. From these beginnings the Morehouse collection has two distinct elements.

Regional land, freshwater and marine molluscs, collected by her and colleagues.

Elsie Morehouse was a very active field naturalists recording and collecting mostly land and freshwater shells. Her collecting was focused #locally but she did travel and received shells from her many acquaintances. She corresponded with experts of the day and many of her shells have been identified by them. Notable correspondence is that with J.W. Taylor (1845-1931) (Boycott, 1931) (Figure 4), Chas Oldham [1868–1842] (Anon. 1943) A.W. Stelfox (1883–1972) (McMillan, 2004) (Figure 4) and A.E. Boycott (1877–1938) (Oldham, 1938). These letters are dated from as early as 1920 and some like that of J.W. Taylor's indicate that Elsie was very much the "student" at this time. She was sending specimens for verification as well as receiving them for her own collection.

There are many lots in her collection coming from Fred Taylor (1871–1949) (Jackson, 1949) (Figure 5A) whose collection in part went to another acquaintance, John Armitage of Leeds (1900–1996) (Norris, 1997). Many of these lots predate Elsie's period of activity and therefore may or may not have come directly to her. Other sources marked on the boxes include Fred Booth (a Bradford collector) (Figure 5B) and H. Sowden (1870–1936) (Gayner, 1937), but there remain a number whose identity requires further research.

Of these there are a number of glass-topped pill boxes containing molluscs from Dog Holes Cave, Warton Crag (Figure 5C). It is likely that these are ex J.W. Jackson (1880–1978) (McMillan, 1970) who wrote the reports (Jackson, 1909/10) and later corresponded with Morehouse.

Elsie would appear to have some favourite collecting sites among them Askham Bog, close to York. Her early records from this and other sites are of significance in assessing temporal changes and most can be verified from specimens in her collection. It is likely that her notebooks recording her finds are as important as the specimens themselves.

Although her marine specimens are fewer, there are one or two rarities, but I do not believe that Morehouse collected these herself but acquired

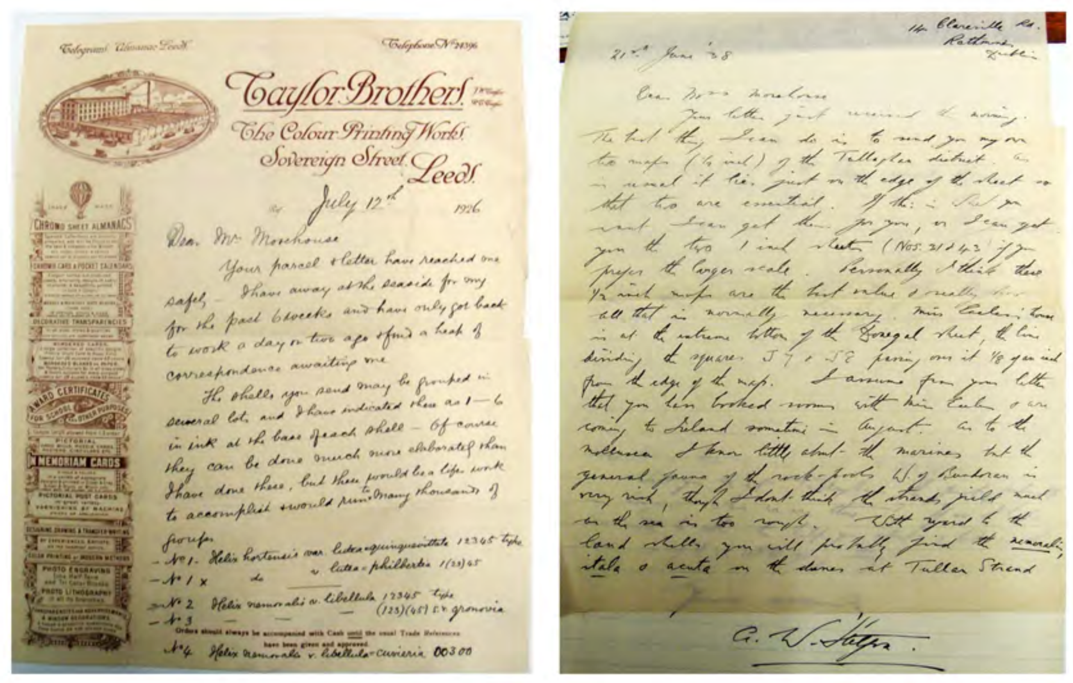


Figure 4. Examples of letters between Elsie Morehouse and recognised conchologists. Left from J. W. Taylor. Right from A. W. Stelfox. © Doncaster Museum and Art Gallery.

Figure 5. Examples of land snails exchanged from other collectors. A, Fred Taylor. B, Fred Booth. C, J.W. Jackson. © Doncaster Museum and Art Gallery.

them from other sources, perhaps directly from Hargreaves or Gyngell. Notable here are examples of *Beringius turtoni* (Bean, 1834) (Figure 6A) collected "36 miles NE by E of the Tyne, 50 fathoms"and *Liomesus ovum* (Turton, 1825) (as *Buccinopsis dalei Sowerby, 1825*) (Figure 6B) *38.4* miles ENE of Tyne".

Figure 6. Two rare marine gastropods from off Northumberland. A, Beringius turtoni. *B,* Liomesus ovum. *© Doncaster Museum and Art Gallery.*

Foreign mollusca acquired via FC North or by exchange or purchase

This portion includes all the major families of the Bivalvia and Gastropoda plus a small number of Polyplacophora. The dominant group are the gastropods and these can be further divided into non-marine and marine groups. Given the range of species and storage condition it is apparent that the land snails were Elsie Morehouse's favourite subject. She exchanged with a number of American and Australian collectors and these can be found listed in one of Elsie's notebooks.

Tropical Land Snails

The collection contains fine examples of species from the Pacific Islands, those most frequently mentioned being Hawaii, Solomon Islands and New Hebrides. There are also shells from the Philippines, Cuba and Florida with some representation from the Indian subcontinent and Africa.

Groups that are well represented are *Achatinella* (Figure 7), *Partula*, *Papuina*,(Figure 8) *Cerion*, *Liguus*, *Helicostyla* (Figure 8) and Cyclophoridae. The island faunas that many of these shells represent have been ecologically degraded and many land snail species are now endangered. On Hawaii and some of the Society Islands many have become extinct. The Hawaiian achatinellids have suffered considerably (Yeung and Hayes, 2018) and it is not surprising that some extinct species are represented in the Morehouse collection; *Achatinella decora casta* (Newcomb, 1854) and *A. abbreviata* (Reeve, 1850) are examples. At least one lot came from an eminent collector, D.D. Baldwin who lived in Hawaii and whose collection is now primarily in the B.P. Bishop Museum, Honolulu. Baldwin (1831–1912) (Anon, 1913) died in 1912 so Morehouse must have acquired these from a secondary source. A letter (Figure 7) in the archive throws light on this and indicates that Morehouse got the shells from R.H. Moses (1871–1949) (Blok, 1949) who himself got them from J. R. le B. Tomlin (1964–1954) (Trew, 1990). Indeed, there is a large series of achatinellids in Tomlin's collection in the National Museum of Wales and probably also in that of Moses now in the Haslemere Museum. Present among the cyclophorids are boxes of *Opisthostoma*, minute, but incredibly shaped shells restricted to Borneo. *Opisthostoma mirabile* and *O. decresipgnyi* are critically endangered (Schilthuizen and Vermeulen, 2004).

Boxes in in one cabinet contain a number of packages with many shells in them and appear to be examples of the samples as they arrived from exchange (Figure 8). These boxes would benefit from further sorting to assess their true content and worth.

This portion of the Morehouse collection warrants a more detailed examination to ascertain the extent of the presence of species of conservation concern. This can only be done with access to the Red Data lists and the malacological literature.

Bivalves

This portion of the collection is contained within a

Figure 7. Achatinellidae from Hawaii. Letter from RH Moses to Elsie Morehouse indicating that shells came from Tomlin. Right upper, part of a drawer of Achatinellidae in the Morehouse collection. Right lower Achatinella shells with the labels of D. D. Baldwin. © Doncaster Museum and Art Gallery.

Figure 8. Examples of tropical land snails from the Morehouse collection. A, species of Helicostyla *from the Philippines, large label is ex Tomlin. B, a selection of Camaenidae many from the Solomon Islands. C, various boxes of unsorted shells from Solomon Islands, Ecuador and Cuba. © Doncaster Museum and Art Gallery.*

48-drawer cabinet. The collection is not greatly representative of the group and contains few areas of possible significance. There are, however, seven drawers of freshwater unionids that do warrant further research. A problem with this portion is that it is difficult to assess their origin and many of the shells have no indication of provenance and may not have come from Morehouse. Some are marked "ScM" (Scarborough Museum), "CH" (Chelmsford Museum) and DM" (Doncaster Museum) but many are not. One or two are marked "ex Carl Mus" (Figure 9), which I take to

Figure 9. Freshwater American unionids in the Doncaster Museum. Top left, Quadrula fragosus *an endangered species ex Carlisle Museum. Top right, part of a drawer with* Lampsilis higginsii, *an endangered species arrowed. Lower right, the endangered* Cumberlandia monodonta. *© Doncaster Museum and Art Gallery.*

"Ex Carlisle Museum" as this agrees with the card index. Regardless of their origins many of the shells are well localised and have the appearance of 19th century labelling. As with the tropical land snails, many American unionids have suffered extinction and many are now on conservation lists. Some of the shells illustrated here (Figure 9) can be found on the US Fish and Wildlife Service lists of endangered species (Böhm, *et al.*, 2021): *Unio fragosus Conrad, 1835* (now *Quadrula fragosa*), *Unio soleniformis* Lea, 1831 (now *Cumberlandia monodonta (Say, 1829)*) and *Unio* (now *Lampsilis*) *higginsii* Lea, 1857.

The remainder of the Morehouse bivalves are unremarkable except for a few lots acquired from her eminent friends in London, notably H. C. Fulton (1861–1942) (Salisbury, 1943) who at that time was dealing with the remains of the stock of G. B. Sowerby III (Petit, 2009). There are also shells from R. Winckworth and determinations by J. R. le B. Tomlin. These malacologists are responsible for much of the content in our national museums in London, Cardiff and Edinburgh.

It should be apparent that the conchological world during the early part of the twentieth century was dominated by gentlemen collectors, dealers and some museum professionals, but very few women were part of this group. Elsie Morehouse was an accepted member of this group and the detailed letter to her from Robert Winckworth (Figure 10) shows how willing he was to help her develop her collection.

Marine Gastropods

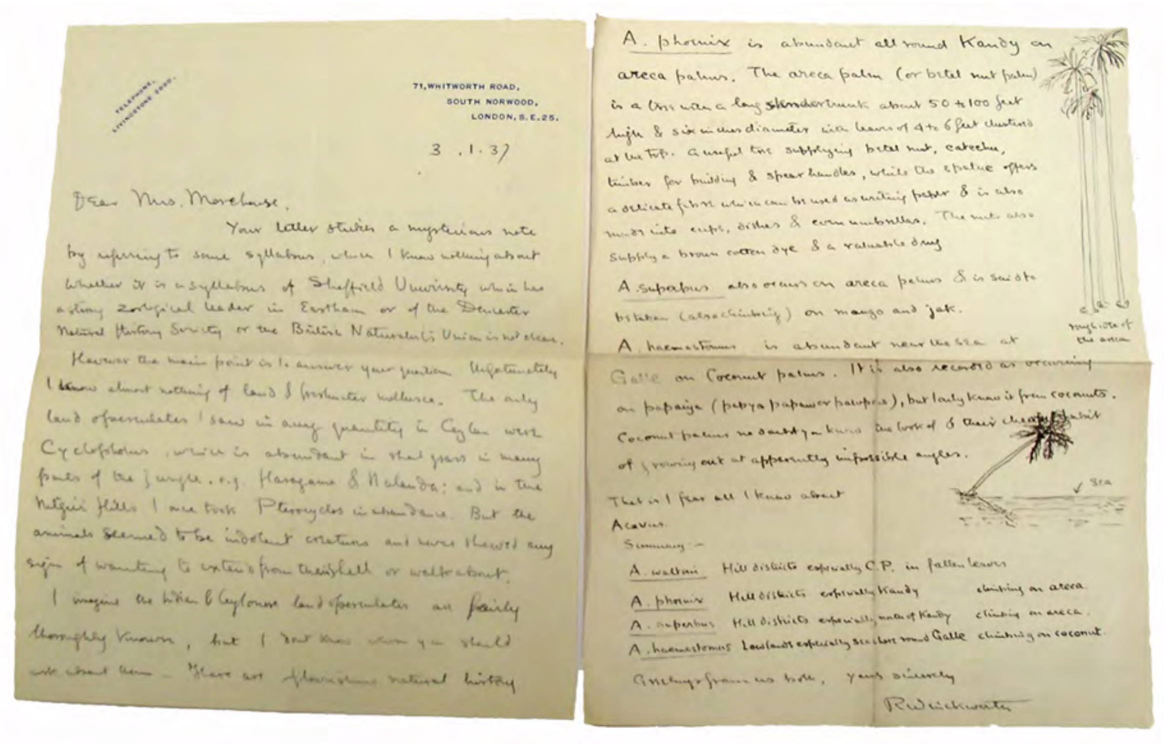
Although 48 drawers of Cabinet 1 and the entire 24 drawers of Cabinet 4 are given over to marine gastropods this part of the collection is unremarkable and indeed much of it is in poor arrangement. Recognisable Morehouse material is mostly in glass topped boxes but many of the loose shells could be from that collection. There appears to be very little indication of scientific or historic relevance but the cone (Conidae), cowrie (Cypraeidae) and volutes (Volutidae) may contain some shells of monetary value on the collectors' market.

Collections transferred from other museums

In the card index Peter Skidmore records that a number of museums transferred whole or in part their collections of molluscan shells. No rationale to these transfers is made but all relate to the period of the 1960s when E.F. Gilmour was Director.

Scarborough Museum

In the card index, reference is made to the transfer


TELEPHONE, LIVINGSTONE 2090.

71, WHITWORTH ROAD, SOUTH NORWOOD, LONDON, S.E.25.

3 .1. 37

Dear Mrs. Morehouse,

Your letter strikes a mysterious note by referring to some syllabus, which I know nothing about. Whether it is a syllabus of Sheffield University which has a strong Zoological leader in Eastham or of the Doncaster Natural History Society or the British Naturalists' Union is not clear.

However the main point is to answer your question. Unfortunately I know almost nothing of land & freshwater mollusca. The only land operculates I saw in any quantity in Ceylon were Cyclophorus, which is abundant in that genus in many parts of the jungle, e.g. Hasagama & Nalanda; and in the Nilgiri Hills I once took Pterocyclos in abundance. But the animals seemed to be indolent creatures and never showed any sign of wanting to extend from their shell or walk about.

I imagine the Indian & Ceylonese land operculates are fairly thoroughly known, but I don't know where you should write about them. Have not [illegible] natural history

A. phoenix is abundant all round Kandy on areca palms. The areca palm (or betel nut palm) is a tree with a long slender trunk about 50 to 100 feet high & six inches diameter with leaves of 4 to 6 feet clustered at the top. A useful tree supplying betel nut, catechu, timber for building & spear handles, while the spathe offers a delicate fibre which can be used as writing paper & is also made into cups, dishes & even umbrellas. The nuts also supply a brown cotton dye & a valuable drug.

A. superbus also occurs on areca palms & is said to be taken (also climbing) on mango and jak.

A. haemastomus is abundant near the sea at Galle on Coconut palms. It is also recorded as occurring on papaiya (papya papaw or pawpaw), but lately known is from coconuts. Coconut palms no doubt you know the look of & their characteristic habit of growing out at apparently impossible angles.

That is I fear all I know about Acavus.

Summary:–

A. waltoni Hill districts especially C.P. in fallen leaves

A. phoenix Hill districts especially Kandy climbing on areca.

A. superbus Hill districts especially north of Kandy climbing on areca.

A. haemastomus Lowlands especially sea shore round Galle climbing on coconut.

Greetings from us both, yours sincerely

R Winckworth

Figure 10. Letter from Robert Winckworth to Elsie Morehouse, dated 1937. © Doncaster Museum and Art Gallery.

of shells from Scarborough to Doncaster, including some of the collection of William Bean (1787-1866). Throughout the collection most of the larger shells with this provenance have “ScM” written on them, often rather boldly in marker pen. There is no documentation and no accession allocation.

The lots from the Bean collection are not marked as such and can only be recognised from the label styles. The majority carry labels in Bean’s own hand and this is confirmed from the biography given by McMillan and Greenwood (1972).

William Bean was an eminent collector and had a large and important collection that was consulted by many authorities of the day and included species described by Bean himself. Given the scientific and historical value of Bean’s collection it is surprising that significant material had been included in the transfer and the cursory examination made for this review uncovered some remarkable material.

The label of *Pedum spondyloideum* (Gmelin, 1791) carries a typical black-bordered label in Bean's hand (Figure 11A) and came from G. B. Sowerby and carries a label with data identical to that found in Sowerby, 1847 (p.438, pl. 41, 1-4). It is possible that the shell is the white variety in figure 3.

The specimen of *Pecten aculeatus* in Fig.11 B was also figured by Sowerby, in his *Thesaurus Conchyliorum* (1842, p. 71, pl. 13 fig. 47) (Figure 11C) but it had been described by Jeffreys in 1839 (p. 40) but was not illustrated.

Modiola cuprea was described by Jeffreys in 1859 having been sent the shells from William Bean. Bean had received these shells from a taxidermist who had retrieved them from the crop of a bird, either a sanderling or a brent goose. These shells were researched by Oliver (2012) and shown to be a Magellanic species belonging to an entirely different family, the Philobryidae and not the Mytilidae.

Another lot from the Bean material in Doncaster was the subject of a second paper by Oliver (2015) who showed that this was the first record of the alien American dreissenid mussel found in the British Isles.

Also present are small card trays with an assortment of label styles some accompanied by Bean labels. Those labelled Mazatlan are probably from P. P. Carpenter who was a contemporary of Bean and lived in Warrington. Other labels have an origin in the Smithsonian (United States National Natural History Museum) stating that the shells had been identified by the famous early 19th century collector Hugh Cuming, but some cannot be traced without further research (Figures 11C-D).

The scale of the Bean material in Doncaster is considerable and can be assessed in the number of

Figure 11. Some shells from the Bean collection, ex Scarborough Museum. A. Pedum spondyloideum *from G. B. Sowerby. B. Figured shell of* Pecten aculeatus *in Sowerby's Thesaurus Conchyliorum of 1842. C. copy of the illustration in Sowerby, 1842. D. E. examples of shells apparently from the Smithsonian Institution in Washington, DC. © Doncaster Museum and Art Gallery.*

lots carrying his distinctive labels. In one drawer alone, The scale of the Bean material in Doncaster is considerable and can be assessed in the number of lots carrying his distinctive labels. In one drawer alone, I recognised eight such labels and a curatorial priority should be to itemise all such lots in the collections. The entirety of the Bean material in Doncaster could not be researched to the detailed levels above but the examples used here illustrate that significant historic material is present and warrants continued investigation.

The Scarborough shells that are not attributable to William Bean have little or no scientific value. I find it difficult to understand why Scarborough Museum would part with shells from the Bean collection. One can, perhaps, believe that a reference series was being developed in Doncaster at a time when the representation of the Mollusca was poor. In contrast there appears to be no reason to acquire the obscure material in the small trays and given its conservation state it would never appear to have been examined.

Worksop Museum Collection

There is no documented list of the material acquired from Worksop and elucidating the original sources of that collection is made more difficult by the closure of Worksop Museum in 1974. The only indication of this material in Doncaster is the letter "W" written on the larger shells or by inference via the card index. Of the larger shells they appear to be no more than exemplars and carry very little data. They have often been amalgamated into single lots with others of the same species from Chelmsford, Doncaster and Scarborough collections.

Fig. 12. Two lots from the Worksop Museum collection both indicating that they were examined by Tomlin. © Doncaster Museum and Art Gallery.

From the card index it is suggested that a large series of shells attached to a thick cream coloured card (Figure 12) is ex-Worksop Museum. One of these cards is attached to a label autographed by Adrian Norris of Leeds Museum suggesting that it is ex-Charles Allen collection. Charles Allen was a collector from Yorkshire who collected mainly land and freshwater molluscs and whose main collection is in Leeds Museum. Many of these cards are annotated indicating that the shells were identified by J. R. le B. Tomlin around 1932–1934 (Figure 12).

Chelmsford Museum Collection.

Once again there is no documentation from Chelmsford indicating the original collector. There is a list itemising the shells. In general, the material is in poor condition and stored loose or in shallow trays. Most of the specimens have "CH" written on them but those in trays do not. Again, working from the card index and the list it can be assumed that those trays carrying pale coloured mauve or turquoise labels with large capitalised text are from Chelmsford (Figure 13). There is very little of

Fig. 13. Mauve and turquoise labels indicative of the Chelmsford collection in Doncaster.
© Doncaster Museum and Art Gallery.

significance in this collection primarily because the locality data are so poor and often contradictory.

Minor collections

Patterson Collection

This collection was donated to Doncaster in 1965 by J. A. Patterson of Bentley, Doncaster. There is no indication of its size but appears to be of tropical marine species with little significance.

Parkin Collection

This was donated by Mr. William Parkin in 1975 and in the register is listed as being housed in 168 assorted boxes. Some of these are incorporated into the drawers but many were found in a large box kept in cupboard. These have had the accession number written on them (1975.258) and many are very distinctive "brass" plated tin circular and rectangular glass topped boxes. Rather surprisingly many of the lots date from the 1880s and collected for example at York, Oldham and Kent.

Barlow/E. E. Gregory Collections

This was donated in 1976 under the accession number 540.76.10, by a Mr. M.C. Barlow but the shells were collected by E.E. Gregory (1861-1937). This is a small collection of British molluscs and was found in a box in a cupboard. A Mr. Gregory is mentioned in Morehouse's obituary (McMillan, 1969).

Discussion

The collections in Doncaster have significance in three main areas.

Regional biodiversity assessment

Both Hargreaves and Morehouse collections represent a 'three dimensional' record of the molluscan fauna of Yorkshire and the north of England. It should be remembered that such collections are the only resource that can be checked to validate past biodiversity records. They record past distributions and are therefore integral to understanding faunistic change that may be natural or anthropogenic, such as climate change. Taken together with other regional collections, such as those in Leeds and Scarborough, an extensive verifiable biodiversity resource exists that could add considerably to the records held on the National Biodiversity Network.

Part of the UK molluscan research resource

The Morehouse collection reflects the interconnectedness of the early twentieth century world of collectors and collections. It was during that period that our national and larger city and university museums acquired the bulk of their collections. The collections of Tomlin and Salisbury form the core of the collections in the National Museum of Wales and National Museums of Scotland respectively. Winckworth's collection went to the Natural History Museum in London as did much of Fulton's stock. The Manchester Museum collection was augmented greatly by Robert Standen, he and all of the above played a part in helping Elsie Morehouse to develop her interest and collection. The days of such widespread collecting have faded, making all our molluscan collections part of an irreplaceable global resource. It is very likely that many of Elsie's tropical land snails are now difficult or impossible to acquire and may not be present in any museum in the countries they were collected from.

In a recent paper on the Linter collection in Exeter, Morgenroth *et al.* (2018) recognised seven syntypes of *Opisthostoma linterae* with three more in the Natural History Museum, London. In the Morehouse collection are another eight (Figure 14) also collected from the type locality. Thus, a total of 18 are available from which variability and similarity to other species can better be assessed. These are accompanied by letters from experts on the taxonomy, A. J. Peile (1868–1948) Winckworth, 1949) and F. F. Laidlaw (1876–1963) (Dance, 1964) and together illustrate the connections between collections and collectors.

Nature is dominated by variation and having good series of examples of each species is the only way that we can recognise it and assess it. A 'one of each' approach to natural history objects would relegate their value to not much more than curiosities.

Much of the Morehouse collection adds to our national resource and should be available via the Global Biodiversity Information Facility.

Social history, history of collecting and collectors.

Collections are made by people and reflect the social conditions of the times that they were created (for example see Oliver and Pegg, 2021). They help to reflect on the individuals and the sense of places in which they were formed. Both J. A. Hargreaves and Elsie Morehouse were ardent Yorkshire folk, and both played an important part in developing natural history societies, biological recording programmes and the establishment of

Figure 14. Opisthostoma shells as an example of the connections between collections and collectors. Top left, a letter from A. J. Peile. Top right, a letter from FF Laidlaw. Lower left and shell, Opisthostoma linterae *part of the type series. Lower Right examples of two red listed species,* O. mirabile *and* O. crespignyi. *© Doncaster Museum and Art Gallery.*

nature reserves. Their stories are worth telling and their collections reflect their lives. Elsie Morehouse was one of only a few women who made a large collection and contributed greatly to an understanding of her local fauna. There is a story to tell about her.

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The value of museum and other uncollated data in reconstructing the decline of the chequered skipper butterfly *Carterocephalus palaemon* (Pallas, 1771)

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Abstract

The chequered skipper butterfly *Carterocephalus palaemon* (Pallas, 1771) was declared extinct in England in 1976 after suffering a precipitous decline in range and abundance during the 20th Century. By searching and collating museum and other records, we show how a deeper understanding of this decline can be achieved, thus furthering conservation objectives. A preexisting Butterflies for the New Millennium (BNM) database of United Kingdom butterfly species records, created by Butterfly Conservation in conjunction with the Biological Records Centre (BRC), contained 266 historic *C. palaemon* records from England. United Kingdom (UK) museums and natural history societies were contacted for specimen data, and these sources added 2175 new records to the BNM. Owners of private specimen collections were also contacted, and these collections accounted for a further 465 records. Specimens originating from UK museums, other institutions, and private collections represent 2640 (71%) of total new records. Other sources, such as personal accounts held in museums, published and unpublished texts produced an additional 894 records. A further 437 records from museums, private collections, and other sources were considered partial and omitted from the data due to limited or misleading date and/or locality information. In summary, data from UK museums and other sources has infilled English *C. palaemon* distribution prior to 1976, offering further insight into potential environmental and anthropogenic drivers of decline at key sites. The quality and quantity of data obtained using the method outlined in this study suggests similar work could be carried out for other extinct or declining butterfly species to improve our knowledge of habitat requirements and historical distribution via modelling, identify causes of decline, and provide valuable information for potential reintroductions.

Keywords: Chequered skipper, *Carterocephalus palaemon*, butterfly, ecology, conservation, museum, collections, natural history

Introduction

In order to reconstruct the historic decline of a butterfly species, long-term data must be collected to understand the extent to which various environmental and anthropogenic drivers may have affected its abundance and distribution. Although there is a growing body of literature on the value of museum specimens for conservation of many different species (e.g. ; Roy, *et al.*, 1994; Shaffer, *et al.*, 1997; McCarthy, 1998; Krupnick and Kress, 2005; Nakahama, 2021), museums have been underutilised as sources of information for declining or extinct butterflies such as the English chequered skipper *Carterocephalus palaemon* (Pallas, 1771) (Dockerty and Cook, 2020; Nakahama, 2021).

C. palaemon (Figure 1) was declared extinct in England in 1976 after experiencing a precipitous decline in the 20th Century, caused by factors such as coppice abandonment, agricultural intensification, and coniferisation (Collier, 1986; Warren, 1990; Ravenscroft, 1995; Moore, 2004). Despite being a prominent case of an insect going nationally extinct, the decline of *C. palaemon* in England is not well documented despite studies by Collier (1966, 1984), Farrell (1973), Ravenscroft (1995), and Moore (2004) due to a paucity of hard data. In order to understand how a restricted, but once locally abundant butterfly could be lost, a research collaboration between the University of Northampton and Butterfly Conservation to complement the reintroduction of *C. palaemon* to Rockingham Forest, England, was established to collect historic *C. palaemon* date and locality information from museum and private collections, personal accounts, and other sources of uncollated data.

Methods

Data collection

Messages requesting historic English *C. palaemon* records from institutions and private collectors were published on social media and circulated to Natural Sciences Collection Association (NatSCA) JiscMail discussion list (natsca@jiscmail.com) subscribers (Jisc, 2021). *C. palaemon* specimens listed for sale were located on an e-commerce

Figure 1. Male C. palaemon in Rockingham Forest, May 19th 2019. © David James.

website (eBay, 2021), and their sellers contacted via private message to request data from any further specimens in their possession. Requests were also made on a blog post, during a presentation to the general public (Wildman, 2020; 2021a), and on social media (Wildman, 2021b). Every attempt has been made to verify the authenticity and source of records and eliminate duplicates. Time and locality data from specimen labels were interpreted as records of sightings. For textual accounts, where abundance of *C. palaemon* at a specific locality in a given year was unable to be precisely quantified (e.g. John Keith Bates' June 5th 1949 diary entry states that 'quite a number of chequered skippers' were at Wakerley Wood [Bates c. 1945-1950]), a single record was included to indicate presence to avoid overestimation. Consequently, historical abundance at many sites has been underestimated (see Farrell, 1973).

Data from museums and private collections were provided in the form of photographs, spreadsheets, and scans of record cards. Label data was transcribed from photographs and record card scans remotely by J.P. Wildman, by museum staff on-site, or, in the case of a substantial private collection in Wiltshire, volunteers acting under instruction. Museums were emailed to inquire whether they held *C. palaemon* specimens. Data was sourced from private, unpublished sources (e.g. J.C. Dale c. 1810-1830; Bates c. 1945-1950), published sources (e.g. Ryland *et al.*, 1902; Macqueen, 1969; Archer-Lock, 1982; Duddington and Johnson, 1983), local researchers (e.g. Adrian Russell), and hobbyist butterfly collectors as well as museums. Data was obtained from 40 UK institutions (including museums, collections centres, natural history societies, universities, and trusts) and one United States (US) museum for this project (see Appendix I).Where collected museum or other uncollated data duplicated records already present in the BNM database, they were omitted from this study.

Dataset creation

A database was created in Microsoft Excel and all records meeting quality control standards were added. Every record was assigned a unique identification number to avoid confusion with other records and duplication. Columns were given the following headings and completed for each record: decade, , date (dd/mm/yyyy), county of origin, vice county number, nearest known locality, OS grid reference, type and source of record (MS = museum specimen, PS = private specimen, UP = unpublished text, PU = published text, BNM = existing data), present location of data, recorder name, collector name, reference (if from a textual source), museum collection name, and notes. Northamptonshire and Cambridgeshire localities were assigned 6-figure OS grid references (10-figure for small sites) based on Northamptonshire Site Register (James, *pers. comms.*) and Bird Club Gazeteer (Cambridgeshire Bird Club, 2021) lists respectively.

Butterflies for the New Millennium (BNM) – a butterfly recording scheme organised by Butterfly Conservation and the Biological Records Centre (BRC) in the United Kingdom (UK), and the Dublin Naturalists' Field Club in the Republic of Ireland – was developed in 1995-99 to assess the status of all native species for *The Millennium Atlas of Butterflies in Britain and Ireland* (Asher *et al*., 2001). Historical records dating back to the 17th Century and records collated by the BRC for a previous atlas (Heath *et al*., 1984) were incorporated. Since 1995, it has operated as the UK recording scheme for distributional 'casual' records and now holds over 14 million records (Butterfly Conservation, 2021). The data has been used in over 50 scientific research papers (e.g. Warren *et al*., 2001; Thomas *et al*., 2004; Suggitt *et al.,* 2018), and as part of a longstanding series of 'State of Butterflies' reports (Fox *et al*, 2007; 2011; 2015). . Grid references for localities elsewhere in England were generated using the UK Grid Reference Finder website in cases where records lacked existing geographic coordinates. Additional columns were later added to the database to account for changes in sites names, records being assigned to localities in different counties, and grid reference irregularities versus raw data. These were: corrected county, corrected vice county, corrected locality, and corrected grid reference.

Data classification

Lynne Farrell's Joint Committee for the Conservation of British Insects (JCCBI) report on the status of *C. palaemon* in England (Farrell, 1973) was classified as a published text for the purpose of this analysis to differentiate it from personal accounts such as diaries. Even though the report is not the public domain, it was nonetheless printed and circulated amongst JCCBI member organisations after its completion in September 1973. Diaries (e.g. Bates [c. 1945-1950]; Tozer [c. 1937-1970]) held in museums were classified as unpublished texts, the same as privately-owned notebooks (e.g. Fuller, *pers. comms.*; Russell, *pers. comms*.).

Criteria for inclusion and exclusion

Records were considered to have met quality control standards and accepted as complete if they contained date and locality information (e.g. a place name), and originated in England. Naming variations (e.g. checkered skipper, *Papilio paniscus* (Fabricius, 1775)) were also permitted. Records were not accepted if a label's place name could not be confidently matched to a specific locality (e.g. 'Morris Links'). Specimens vaguely labelled with settlements (e.g. 'Corby') were assigned to best-candidate woodland in close proximity using georeferenced historical OS maps (National Library of Scotland, 2021) if the site met the following criteria: a) was >10.9ha in size (equal to the smallest known historically occupied site in England, Barrowden Fox Covert), b) possessed internal ride structure, and c) was not coniferous. If clear and obvious provenance of a specimen could not be established, its locality was not changed. Original label wording was often left unchanged to limit the impact of speculation and personal bias on the dataset and outputs.

Ambiguous specimen labelling was a common practice historically, and often a consequence of the commercial interests of professional dealers outweighing interest in accuracy (Green, *pers. comms*.). Solitary records from outside the accepted geographic range of the species (Rockingham Forest and Lincolnshire) were accepted to illustrate the stated locality of all records, but must be treated with some caution (Blathwayt, 1925; Turner, 1955; Mendel and Piotrowski, 1986; Fuller, *pers. comms*.), as eggs and larvae collected from well-known colonies may have been labelled with their breeding and/or release location instead (Green, *pers. comms*.). This may account for isolated records from Kent, Somerset, Buckinghamshire, and West Sussex. Several collectors were resident in these vice-counties around the time records exist: Edgar James Hare (1884-1969) in London and latterly, Kent, William Holland Ballett Fletcher (1852-1941) in West Sussex, Archdale Palmer Wickham (1835-1935) in Somerset, and Cyril Humphrey Cripps (mid-20th Century) in Buckinghamshire. Wild caught and bred specimens could also be purchased from commercial dealers, particularly in the late 1800s-early 1900s (Allan, 1943; Salmon, *et al*., 2000; Fuller, *pers. comms*.). Such records could be interpreted as hoaxes, cases of misidentification, or unsanctioned releases following captive breeding/rearing or translocation. Partial records were omitted from the data.

Data visualisation

For the purpose of this article, plots and tables were created in Microsoft Excel, and the dataset subsequently exported to Quantum Geographic Information System (QGIS) (QGIS Development

Team, 2021) as a csv file for distribution mapping. The Field Studies Council (FSC) Biological Records Tool (TomBio Tools, 2021) was used to translate EPSG:4326 – WGS 84 CRS to British EPSG:227700 – OSGB 1936 / British National Grid CRS and the data plotted as circular points on a Watsonian Vice County Boundary NBN Shapefile using 2km tetrads.

Results

Museums and natural history society specimens that met quality control standards provided 2175 new English *C. palaemon* records. Specimens in private collections accounted for a further 465 new records.Specimens originating from museums, other institutions, and private collections represent 2640 (71%) of total records. Other sources, such as personal accounts held in museums, published and unpublished texts produced an additional 893 records. A further 437 records from museums, private collections, and other sources did not meet quality control standards and were omitted from the data due to limited or misleading date and/or locality information. Incomplete records that did not meet quality control standards have been retained for future reference, as it is possible the provenance of some specimens could eventually be determined by cross-referencing available data with information from other sources.

The existing BNM database contained 266 records. We added 3533 records through this project—a 1328% increase in known records (Figure 2). UK museum data was principally dated between 1880-1959 (2112 records), with 1940-1949 being the most abundant decade (949 records). Only 39 museum records were dated between 1826 (the oldest specimen) and 1879. The most recent museum specimen was from Monks Wood, Huntingdonshire, collected on the 25th May 1965. Only 24 museum specimens were dated between 1960 and 1976, whereas 285 records belonging to the same time period were obtained from published and unpublished texts (e.g. Collier, 1966; Macqueen, 1969; Farrell, 1973; Fuller, *pers. comms*.) (Figure 3).

A total of 803 UK museums and natural history society specimens were from Cambridgeshire (748) and Huntingdonshire (55) (62% of total records from the vice-counties combined), 250 (65%) from South Lincolnshire, and 924 (58%) from Northamptonshire. In total, 1977 museum specimens belong to these four Watsonian vice-counties. The Natural History Museum, London (NHM) donated the largest number of complete records (681), alongside 92 incomplete records (Figure 4). Magdalene College, Cambridge has 229 records, 213 of which were from Fermyn Woods in Northamptonshire. Peterborough Museum & Art Gallery, Bristol City Museum & Art Gallery, Brighton Museum & Art Gallery, Oxford University Museum of Natural History, and the University Museum of Zoology, Cambridge provided >100 specimens each. Lancashire and Cheshire

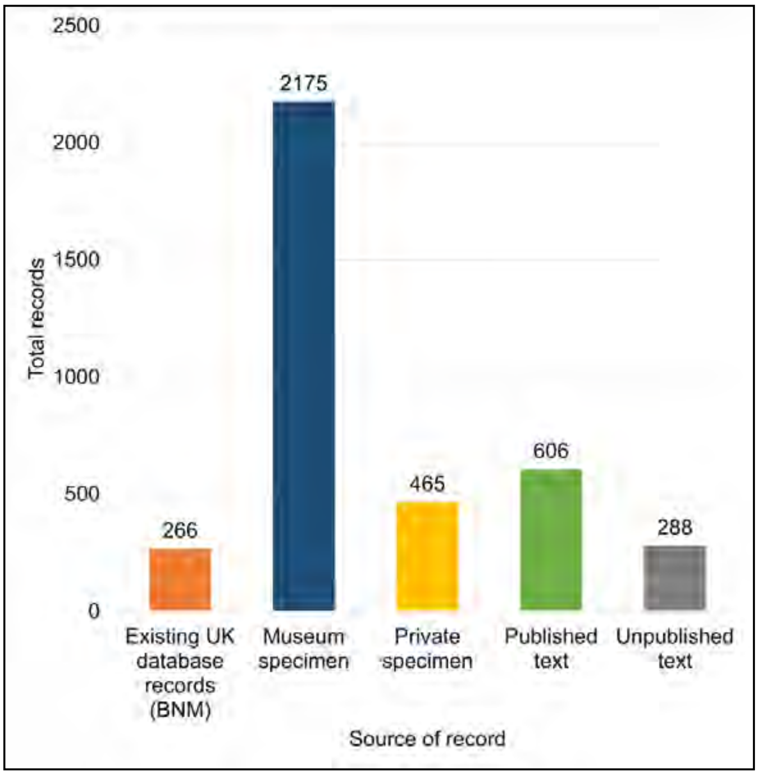


Figure 2. Total English C. palaemon records by data source.

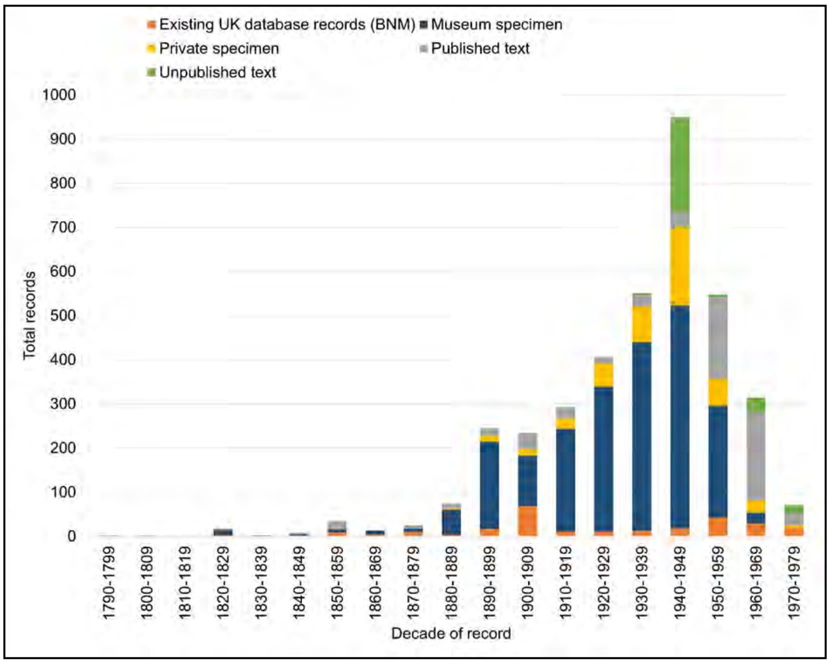


Figure 3. Total English records by decade from all data sources.

Entomological Society data (21 records) is held by National Museums Liverpool. Both Wisbech & Fenland Museum (60 records) and Magdalene College, Cambridge data was supplied by the University Museum of Zoology, Cambridge (Figure 4). Nonetheless, institutions were separated to acknowledge the exact source of all records.

Only one specimen held in a private collection originated from a Rutland site, whereas 39 were from museum collections. Similarly, only 17 South Lincolnshire specimens were held in private collections, compared to 250 in museums. Records originating from Kent, Devon, Dorset, Hampshire, Leicestershire (distinct from Rutland, the location of the Luffenham Heath sub-landscape near Barrowden and Wakerley Woods), Norfolk, and Oxfordshire were obtained from museums, but these vice-counties were not represented in any private collections. Specimen data from Derbyshire and Worcestershire (3 records total) were the only vice-counties represented by private collections not known to be present in any museum collections. BNM data is dwarfed by new

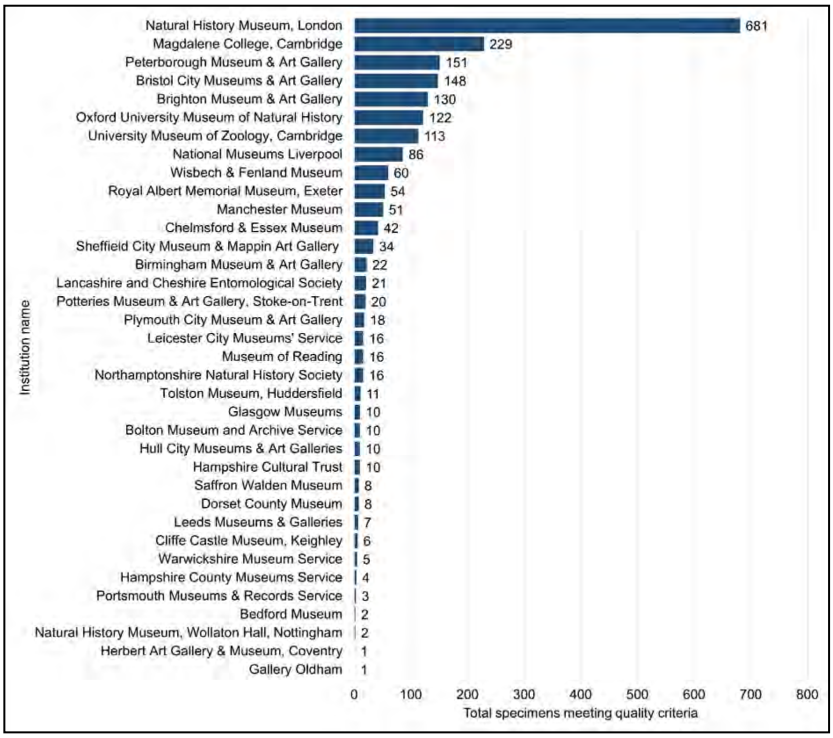


Figure 4. Total English specimens from institutions meeting quality control standards.

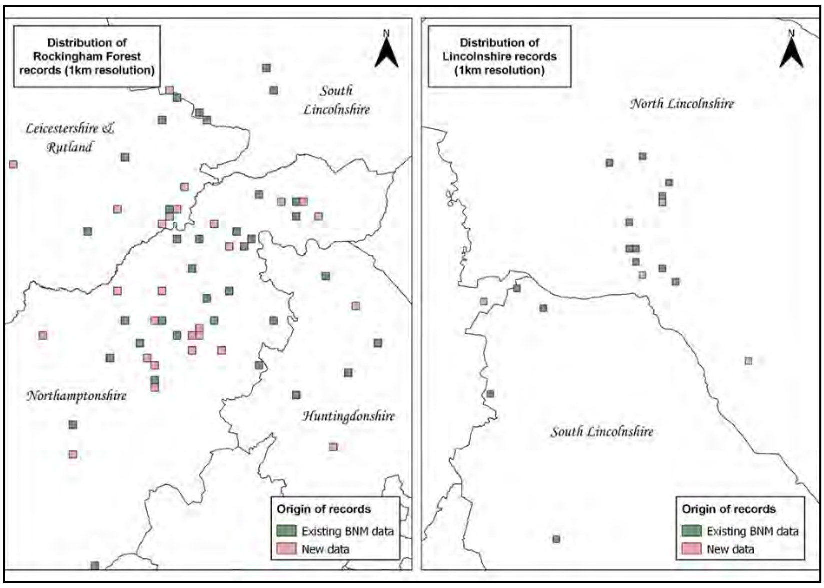


Figure 5. C. palaemon distribution in Rockingham Forest and Lincolnshire, 1798-1976.

data at all major English sites. New data also confirmed the importance of the Rockingham Forest and Lincolnshire Limewoods landscapes by infilling known distribution (Figure 5).

Data from museum specimens pushed back the first date of known records at 9 of the 20 most populous English sites (Figure 6) with both existing and new museum data. In the case of Great Fen (under which Holme and Woodwalton Fen records were merged), the earliest dated museum specimen attributed to Holme Fen was 1851, whereas the earliest existing database record attributed to Woodwalton Fen was 1950, thus accounting for the 99 year difference in earliest dates of known occupation between the two data sources. The vice-counties of Derbyshire and Kent, and 31 English localities with >1 record (10 with >5 records) were not represented in existing BNM data.

Only two museum specimens meeting quality control standards are dated later than 1964 (both 1965): one is housed at the NHM (BMNH(E): 1381012), and the other at the Royal Albert Memorial Museum, Exeter (RAMM). The NHM specimen, labelled 'G A. M' from Collyweston Great Wood and Eastern Hornstocks, is one of only two museum specimens known to originate from the site. The RAMM specimen (EXEMS: 74/2015/213) was captured at Monks Wood in Huntingdonshire. Three newer specimens (dated 1967-69) did not meet quality control standards as their provenance could not be determined and were therefore excluded from this study. One of a total 14 1964 museum specimens is labelled 'Wigsley Wood' – a Nottinghamshire site 4.47km west-southwest of Skellingthorpe Big Wood in South Lincolnshire. The specimen (BMNH(E) 1363871), collected by 'A. Palmer' and housed at the NHM is both the only Wigsley Wood

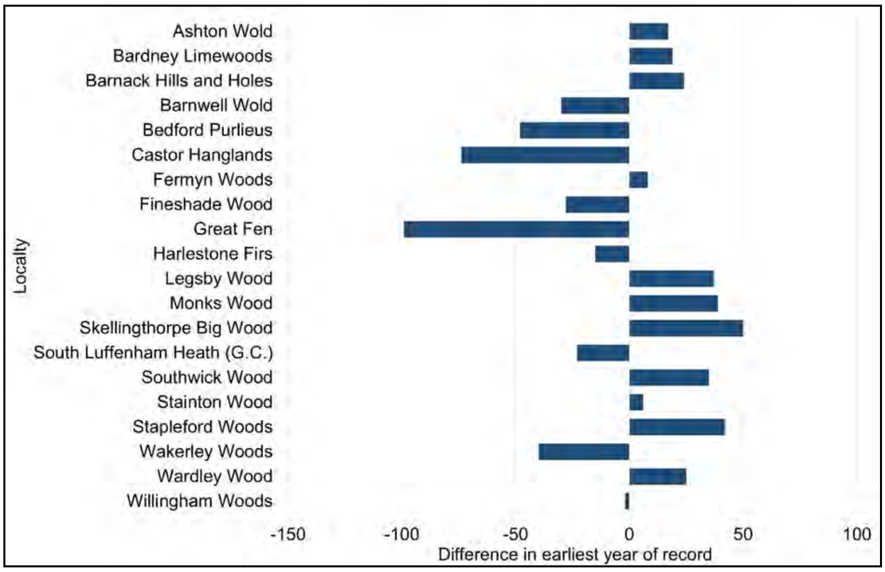


Figure 6. Difference in earliest year of record at most abundant English localities: museum specimens versus existing UK database records (BNM).

specimen and post-1939 record with definitive Nottinghamshire provenance known to exist (a single 1960 private specimen is vaguely labelled 'Nottingham'). J.C. Dale manuscripts at the Oxford University Museum of Natural History push the earliest English record of *C. palaemon* back 5 years to 1798 (at Clapham Park Woods in Bedfordshire) compared to BNM data (at Gamlingay Wood in Cambridgeshire in 1803).

Cyril Humphrey Cripps and 'S.W.' Humphrey collected a combined total of 283 *C. palaemon* at Fermyn Woods between 1942-1944. Magdalene College donated 213 records (all C.H. Cripps) from the site, whilst a single private Wiltshire collection included 70 Humphrey specimens. Sidney H. Kershaw is cited as the collector of 13 additional specimens belonging to the same collection. A total of 41 specimens dated 1940 are unlabelled but considered to have 'almost certainly' been captured by Kershaw because of the way they are characteristically 'badly set' (Clarke, *pers. comms.*). Cripps, Humphrey, and Kershaw's specimens (including unlabelled attributions) accounted for 77% of all records from Fermyn Woods (437). Overall, 136 new Fermyn records were from the private Wiltshire collection, and 268 from museum collections, emphasising the historical significance of the woodland complex in respect to the wider Rockingham Forest landscape. Existing BNM data contained only 10 records attributed to Fermyn.

Cripps, who had an interest in 'rarer' butterflies (St John's College obituaries, 2000), visited Fermyn Woods on May 24th 1942, likely at the emergence peak, and captured 122 *C. palaemon*. On the following day, May 25th, Humphrey collected 33 specimens. Cripps returned to Fermyn in 1943 and collected 55, however there are no 1943 specimens attributed to Humphrey in the Wiltshires collection. On May 24th 1944, Humphrey took 31 *C. palaemon*, whilst Cripps collected 26 four days later on May 28th. Cripps and Humphrey subsequently took a total of 21 *C. palaemon* from Fermyn between 1947-1953. It is not known whether the men were aware of each other, but collectors of the time were considered 'very competitive' (Green, *pers. comms*). Only 10 more recent Fermyn records are known to exist, dated between 1956 and 1964. 312 specimens were collected from Fermyn across 4 flight periods (1940, 1942, 1943, 1944). However, only one specimen – held at the NHM and labelled 'Laudimer' – is dated 1941 (BMNH(E)1365098).

John Keith Bates' diary describes how he, Don Tozer, and Arthur L.Goodson (then of Tring

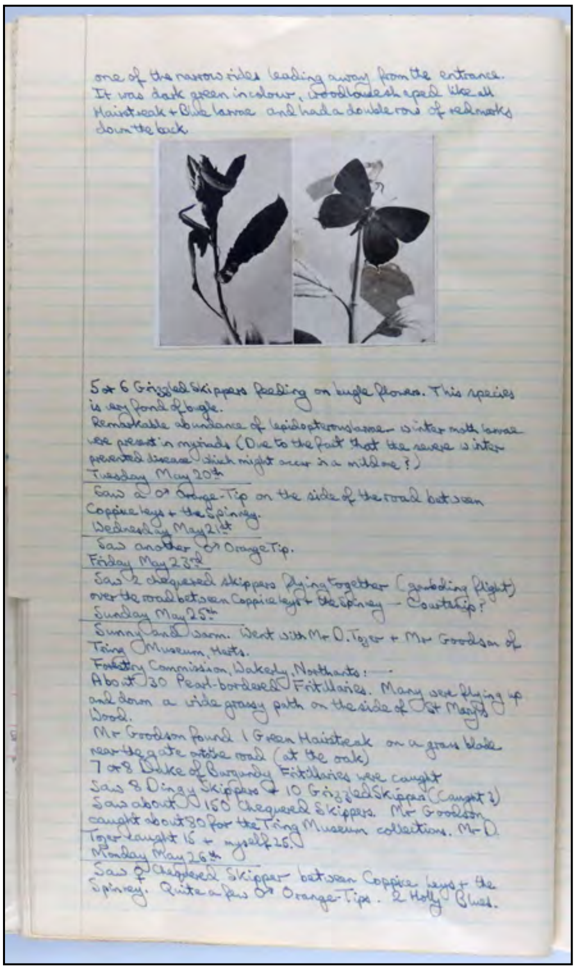


Figure 7. Page from J.K. Bates' diary at Leicestershire County Council Museum Collections in Barrow. © Adrian Russell.

Museum) collected 120 of 150 *C. palaemon* they saw at Wakerley Woods on May 25th 1947 (Figure 7). Bates' accounts are corroborated by the presence of 'A.L. Goodson' and 'D. Tozer' Wakerley Woods specimens from 1947 at the NHM, Glasgow Museums, National Museums Liverpool, and RAMM. However, they collectively number only 27 (23%) of the 120 *C. palaemon* known to have been taken from Wakerley by the trio in 1947.

Discussion

That only 23% of Bates, Tozer, and Goodson's 1947 Wakerley Woods specimens have been located suggests new data from UK museums, private collections, personal accounts, and other sources represents only a fraction of all uncollated data that exists or ever existed. George Sellars' 1972 photograph at Addah Wood, for example, is the only evidence that *C. palaemon* colonised the Rutland site. The original 35mm slide is held in a private collection (Russell, *pers. comms.*) (Figure 8).

Figure 8. Scan of 35mm slide of male C. palaemon photographed at Addah Wood, Rutland, June 1972 by George Sellars. © Adrian Russell and Jamie Wildman.

It is quite possible that a significant percentage of uncollated data – especially those in private hands – has been lost or destroyed, given biological specimens are fragile and vulnerable to pest damage. Bates' diaries make it clear that he collected extensively, yet his collection at Leicester Museum consists of just six drawers and three *C. palaemon* specimens (Figure 9). Tozer's Coleoptera collection and 1937-1970 diaries were also donated to Leicester Museum, but his Lepidoptera collection was sold at auction to a non-entomologist and is now feared lost, as are his 1956-1961 diary entries (Russell, *pers. comms.*). Pratt's collection, containing 319 complete *C. palaemon* specimens, has been placed in storage since label transcription took place.

There is no evidence of mass collecting having taken place at Fermyn Woods after 1944 and Wakerley Woods after 1947, despite *C. palaemon* being described as 'common' and 'fairly plentiful' at Wakerley as late as 1957 (Farrell, 1973). While *C. palaemon* populations remained healthy at key sites, it is unlikely collectors would have been motivated to search for other localities where the butterfly was abundant, as 'only limited availability would have driven a search for new sites' (Clarke, *pers. comms.*). However, in 1948 – the year after Bates, Tozer, and Goodson collected 120 *C. palaemon* at Wakerley – Tozer comments in a May 16th diary entry that there are 'very few Paniscus about & apparently they are quite scarce, but other butterflies abundant.' *C. palaemon* is again described by Tozer as 'scarce' at the site in 1949 (Tozer c. 1937-1970). Bates, however, notes 'quite a number of chequered skippers – not so many as usual at this time of year in other years' in an entry dated June 5th, 1949 (Bates c. 1945-1950). Twenty three *C. palaemon* were caught in 1950 (Farrell, 1973), however none of these specimens have been located during the course of this study. Numbers are only described as 'fair' at Fermyn in 1950 (Farrell, 1973), and only 19 records originate from the complex following this date, compared to 48 from Wakerley.84 textual records from Castor Hanglands (1961-1963), 48 from Luffenham Heath (1968), and 'between 30 and 40' from Skellingthorpe (1953) (Farrell, 1973; Duddington and Johnson, 1983) shows that healthy colonies were documented where present in the 1950s and

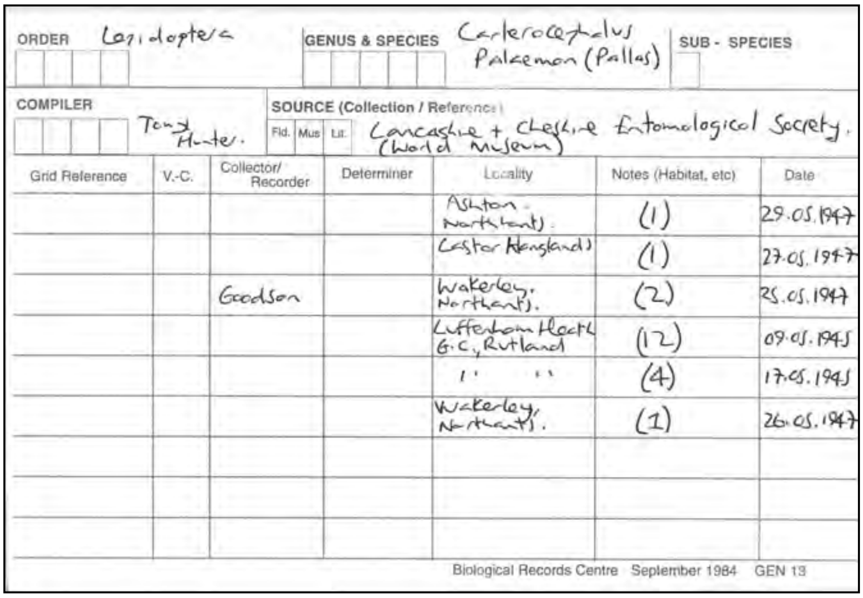
Figure 9. A drawer from J.K. Bates' collection at Leicester County Council Museum Collections in Barrow. © Adrian Russell.

1960s. *C. palaemon* was thought to have been lost from Fermyn by 1961 according to Farrell's JCCBI report (1973), however two 1964 records have since come to light in the BNM database and a published text (Izzard, 2018). The last Wakerley record, however, remains 1961 (BNM).

This is not to suggest collecting is a principal cause of extinction at either Fermyn and Wakerley. Rather, it is an example of a novel, anthropogenic pressure evidenced through museum data that, when combined with major drivers such as coniferisation and coppice abandonment (Moore, 2004; Peterken 1976; Peterken and Harding, 1974; Orchard, *pers. comms.*), may have marginally accelerated decline at both sites. Mark-release-recapture (MRR) studies (e.g. Thomas, 1983; Warren, 1983; Bourn and Thomas, 1993) have shown populations are much higher than causal observations demonstrate, and that collecting is unlikely to drive butterfly species to extinction on sites unless population size has already become very small due to other pressures. Brereton (1997), for example, determined it was possible to remove up to 50% of a population present on one day by MRR when numbers were low (<50 individuals). However, even with intensive sampling, only 5% of a total population could be removed per day. He concedes, however, that the effect of collecting was likely to be slightly underestimated by the MRR programme. The quantity of museum and private specimen data presented in this study merely demonstrates how plentiful *C. palaemon* once was where found, and how unfathomable scenes of '12 in the net at one time' (as was the case at Legsby and Lynwode Woods in 1890) (Farrell, 1973) are in the present day.

The 'large colony' stated to be present at Luffenham Heath golf course in 1968 in Macqueen (1969) and Farrell (1973) indicates a minimum 9-year occupation (1968-1976) of the Rutland site. Compared to existing BNM data, known occupation has now been lengthened to 45 years (1932-1976). Earliest known occupation was initially increased to 32 years (1945-1976) after National Museums Liverpool provided a scanned Lancashire and Cheshire Entomological Society collection record card featuring the wording 'Luffenham Heath G.C., Rutland - (12) - 09.05.1945' (Figure 10). These 12 specimens indicate that the Luffenham Heath area was colonised whilst still continuous heathland known as South Luffenham Heath and Barrowden Leys, 'an expanse of heath grassland and scrub, stretching northeastwards from Barrowden t owards Ketton […] ploughed over by 1950' (Messenger, 1971). Construction of the golf course began in 1909 and finished in 1911. The 1945 specimens also add credibility to 1942-1946 Tozer diary entries, which mention a 'small wood near Barrowden' at which *C. palaemon* was present 'in hundreds' (Tozer c. 1937-1970). The diaries were found at Leicestershire County Council Museum Collections, Barrow (Russell, *pers. comms.*). The 'small wood' was subsequently determined to be Coppice Leys, situated 213m south of Luffenham Heath golf course.

An entry dated May 23rd, 1947 in Bates' diary, also at Barrow, states he saw '2 Chequered Skippers flying together (gambolling flight) over the road between Coppice Leys & the Spinney – Court-ship?' Bates c. 1945-1950. The 'Spinney' in question was subsequently identified as Culligalane Spinney. An image of a 1932 Luffenham Heath


ORDER Lepidoptera GENUS & SPECIES Carterocephalus Palaemon (Pallas) SUB - SPECIES

COMPILER Tony Hunter. SOURCE (Collection / Reference) Fld. Mus Lit. Lancashire + Cheshire Entomological Society. (World Museum)

Grid Reference	V.-C.	Collector/ Recorder	Determiner	Locality	Notes (Habitat, etc)	Date
				Ashton. Northants).	(1)	29.05.1947
				Castor Hanglands)	(1)	27.05.1947
		Goodson		Wakerley, Northants).	(2)	25.05.1947
				Luffenham Heath G.C, Rutland	(12)	09.05.1945
				" "	(4)	17.05.1945
				Wakerley, Northants).	(1)	26.05.1947

Biological Records Centre September 1984 GEN 13

Figure 10. Lancashire and Cheshire Entomological Society record card, featuring 1945 Luffenham Heath specimen data. © World Museum, Liverpool.

specimen labelled with the collector 'Mason, A.G.L.' was later found on an archived eBay listing (Russell, *pers. comms.*). Rather than being an isolated site at which *C. palaemon* merely hung on at in its final years, the broad time span of occupation and quantity of Luffenham Heath Records - comparable to key localities in Rockingham Forest - suggest the site may have driven the metapopulation dynamics of its sub-landscape for several decades, if not longer. Agricultural intensification and insufficient woodland management (Messenger, 1971) is believed to have confined *C. palaemon* to Luffenham Heath by the 1950s. As the earliest known record from the site is dated 1932 - 21 years after construction of the golf course was completed - it is not known whether development of the heathland for recreational purposes had any impact on population health.

A general decline in records beginning in the late 1950s is not considered an artefact of reduced collecting, as the number of specimens from 1956 (134) exceeds the highest total from any year in the 1920s or 1930s. The introduction of collecting restrictions at East Midlands National Nature Reserves (NNRs) from 1964 (Collier, 1986) and increasing scarcity of *C. palaemon* in the 1960s is jointly responsible for lower numbers of more recent specimens. Although few conclusions can be drawn regarding *C. palaemon*'s status after the mid-1960s using specimens alone, museum data has lengthened the known historical occupation of key sites compared to existing BNM data, including Luffenham Heath (the last locality in England at which *C. palaemon* was sighted), Wakerley Woods, Castor Hanglands, Bedford Purlieus, and Fineshade Wood. Importantly, a significant quantity of new data is concentrated around the mid-20th Century - the time when *C. palaemon's* decline in England is believed to have begun (Collier, 1986; Ravenscroft, 1992).

Although most records belong to Rockingham Forest, Rutland, and Lincolnshire, museum data spanning over a century (1829-1938) from the south coast hints at a third concentration of colonies stretching across Devon, Dorset, Somerset, West Sussex, Buckinghamshire, and Kent. It is plausible that *C. palaemon* once occupied the Weald, given it featured the largest area of woodland in Medieval England (Rackham, 2000). Several historic texts indicate Devon, Hampshire, and Dorset occupation (e.g. J.C. Dale c. 1810-1830; Morris, 1853; Westwood, 1854; Newman, 1869;), as do thirteen museum specimens meeting quality control stamdards dated 1886-1938. It is possible that southern colonies were waning even before the advent of butterfly collecting and recording.

C. palaemon was anecdotally regarded as 'very common' and 'in no danger of extinction' as late as 1961 by Pilcher (1961), and 'incomparably more numerous than it was [30 years ago]' at one site in 1957 by Lane and Rothschild (1957). No effort to systematically evaluate the butterfly's status nationwide occurred until Farrell's 1973 JCCBI report, after which the extinction of *C. palaemon* was inevitable. Little mention of a decline in numbers was published prior to *C . palaemon*'s extinction, although Pilcher accepts that the species 'no longer enjoys its former abundance' at Castor Hanglands in 1961 (Pilcher, 1961). Collier (1966) still considers the butterfly to be 'common' there between 1961-65, however.

Conclusion

A majority of *C. palaemon* records provided by museum collections meet quality control standards for inclusion in this study. Anonymous specimens, and those with labels considered incomplete that offer little in the way of new, reliable data are in the minority. Many museums are in the process of digitally cataloguing their butterfly collections to ensure specimens are preserved for future generations to access (Figure 11).

The large increase in *C. palaemon* records has been made possible thanks to the digitisation of museum collection data in the 21st century, and better connectivity between researchers seeking historical data and museums thanks to email distribution lists and social media. Museum data has confirmed the historic range of *C. palaemon* and infilled distribution between 1798-1976 in the species' known Rockingham Forest and Lincolnshire strongholds (Farrell, 1973; Collier,

Figure 11. Digitally photographed C. palaemon specimen housed at the University Museum of Zoology, Cambridge. © University of Cambridge.

1986; Ravenscroft, 1995; Moore, 2004), significantly increased record abundance, and lengthened known time periods of occupation at key sites. The significant contribution museums have made to this study in the form of both specimens and textual archives has allowed us to draw much stronger conclusions about the species' possible rapid extinction in England, and confirmed the roles of anthropogenic and environmental drivers of decline, such as clearfelling of medieval broadleaf woodland, coppice abandonment, high forest conversion, conifer afforestation, habitat fragmentation, and colony isolation, which, although predominately based on circumstantial evidence, are generally accepted (e.g. Farrell, 1973; Lamb, 1974; Peterken and Harding, 1974; Peterken, 1976; Collier, 1978, 1986; Ravenscroft, 1992; Moore, 2004).

This study has focused on documenting the process of collection and collation of new data and presented initial findings. The enhanced dataset will now be used to look in more detail at the relative significance of factors possibly contributing to extinction, not just at landscape-scale, but per site. It will lead to improved knowledge of habitat requirements and generate valuable information for potential future butterfly reintroductions across the Rockingham Forest network, as well as other conservation work such as habitat management. The quantity and quality of uncollated *C. palaemon* data obtained from museum collections and archives demonstrates the vast potential of this source of information for studies of other extinct, threatened, or declining UK butterfly species to improve our knowledge of their historical distribution via modelling, identify drivers of decline and candidate sites for potential reintroductions. Museums should therefore be considered the foremost point of contact for researchers seeking to obtain historic spatiotemporal data for other UK butterfly species that are similarly poorly understood. The method outlined in this study offers a novel approach to accessing data held by museums and other sources of uncollated data that is not available in an easy-to-access form. However, significant time and energy must be invested in order to build a dataset of records comparable to the one we have built for the English *C. palaemon*, given the number of institutions, individual collaborators, sources, and types of raw data that were involved in its creation.

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The Lancaster University *C. palaemon* specimens used in this study belong to a collection made by Edgar James Hare C.B.E. (1884-1969) that were donated by Mrs. Suzanne Hare in his memory.
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Specimens used in this study are held at the following institutions: Bedford Museum (BEDFM), Birmingham Museum & Art Gallery (BIRMG), Bolton Museum and Archive Service (BOLMG), Brighton Museum & Art Gallery (BTNRP), Bristol City Museum & Art Gallery (BRSMG), Chelmsford and Essex Museum (CHMER), Cliffe Castle Museum (BRFMS), Herbert Art Gallery & Museum (COVGM), Dorset County Museum (DORCM), Gallery Oldham (OLDMS), Glasgow Museums (GLAMG), Hampshire County Museums Service (HMCMS), Hampshire Cultural Trust (HMHCT), Hull City Museums and Art Galleries (KINCM), Leeds Museums & Galleries (LEEDM), Leicester City Museums' Service (LEICT), Manchester Museum (MANCH), Museum of Reading (REDMG), National Museums Liverpool (LIVCM), Natural History Museum, London (NHMUK), Natural History Museum, Wollaton Hall, Nottingham (NOTNH), Oxford University Museum of Natural History (OUMNH), Perth Museum & Art Gallery (PERGM), Peterborough Museum & Art Gallery (PETMG), Plymouth City Museum & Art Gallery (PLYMG), Portsmouth Museums & Records Service (PORMG), Potteries Museum & Art Gallery, Stoke-on-Trent (STKMG), Royal Albert Memorial Museum

(EXEMS), Saffron Walden Museum (SAFWM), Sheffield City Museum & Mappin Art Gallery (SHEFM), Tolston Memorial Museum (KLMUS), University Museum of Zoology, Cambridge (CAMZM), Warwickshire Museum Service (WARMS), Wisbech & Fenland Museum (WISFM), and Yale Peabody Museum (YPM).

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Appendix I – Museums and Natural History Societies

Bedford Museum: https://www.thehigginsbedford.org.uk/
Birmingham Museum & Art Gallery: https://www.birminghammuseums.org.uk/bmag
Bolton Museum and Archive Service: https://www.boltonlams.co.uk/
Brighton Museum & Art Gallery: https://brightonmuseums.org.uk/brighton/
Bristol City Museum & Art Gallery: https://www.bristolmuseums.org.uk/
Chelmsford and Essex Museum: https://www.chelmsford.gov.uk/museums/
Cliffe Castle Museum: https://www.bradfordmuseums.org/
Herbert Art Gallery & Museum: https://www.theherbert.org/
Dorset County Museum: https://www.dorsetmuseum.org/
Gallery Oldham: https://galleryoldham.org.uk/
Glasgow Museums: https://glasgowlife.org.uk/
Hampshire Cultural Trust & County Museums Service: https://www.hampshireculture.org.uk/
Hull City Museums and Art Galleries: https://www.hcandl.co.uk/museums-and-galleries/
Leeds Museums & Galleries: https://museumsandgalleries.leeds.gov.uk/
Leicester City Museums' Service: https://www.leicestermuseums.org/
Manchester Museum: https://www.museum.manchester.ac.uk/
Museum of Reading: https://www.readingmuseum.org.uk/
National Museums Liverpool: https://www.liverpoolmuseums.org.uk/
Natural History Museum, London: https://www.nhm.ac.uk/
Natural History Museum, Wollaton Hall, Nottingham: https://wollatonhall.org.uk/hall-and-museum/natural-history-museum/
Northamptonshire Natural History Society: https://www.nnhs.info/
Oxford University Museum of Natural History: https://www.oumnh.ox.ac.uk/
Perth Museum & Art Gallery: https://www.culturepk.org.uk/museums-and-galleries/perth-museum-and-art-gallery/
Peterborough Museum & Art Gallery: https://cityculturepeterborough.org.uk/museum-art-gallery/
Plymouth City Museum & Art Gallery: https://www.theboxplymouth.com/
Portsmouth Museums & Records Service: https://portsmouthmuseums.co.uk/
Potteries Museum & Art Gallery, Stoke-on-Trent: https://www.stokemuseums.org.uk/pmag/
Royal Albert Memorial Museum, Exeter: https://rammuseum.org.uk/
Saffron Walden Museum: https://www.saffronwaldenmuseum.org/
Sheffield City Museum & Mappin Art Gallery: https://www.museums-sheffield.org.uk/
Tolston Memorial Museum https://www.kirklees.gov.uk/beta/museums-and-galleries/tolson-museum.aspx
University Museum of Zoology, Cambridge https://www.museum.zoo.cam.ac.uk/
Warwickshire Museum Service https://heritage.warwickshire.gov.uk/museum
Wisbech & Fenland Museum https://www.wisbechmuseum.org.uk/
Yale Peabody Museum https://peabody.yale.edu/

Dodo remains in the National Museum of Ireland - Natural History, Dublin

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Abstract

Dodo remains in some museums are not well known or publicised. The fossil bones in the National Museum of Ireland are described and their provenance discussed. Dodo remains in Trinity College Dublin and those exhibited at a scientific meeting in Dublin in 1866 are also reviewed. The Dublin skeleton is a composite, mostly acquired by the Royal Dublin Society at auction in London in 1866, and mounted by Edward Gerrard junior in 1871.

Keywords: Dodo, *Raphus cucullatus*, Royal Dublin Society, Science and Art Museum Dublin

Introduction

The National Museum of Ireland - Natural History (NMINH) inherited the collections of the Royal Dublin Society (RDS) in 1877, including a mounted composite partial skeleton of a dodo (Figure 1), and a number of other dodo bones, all from Mauritius. The original documentation for these specimens is sparse and what follows is an attempt to bring together information from a number of sources to shed light on this important collection.

Dodo remains in museums

Dodos (*Raphus cucullatus* (Linnaeus, 1758)) have a long history of being discussed and illustrated in popular publications, mostly focused on evidence from old contemporary accounts of then living birds (Fuller, 2002; Parish, 2013). The surviving hard evidence in museums and private collections relies on a very small number of fragments taken from living birds brought to Europe, and a modest number of fossil bones, most of which are not associated and result in composite skeletons or isolated skeletal elements. Of the popular published accounts of this species there are very significant numbers of pages dedicated to dodo history, illustrations, cultural significance, and extinction (Fuller, 2000, 2002, Parish, 2005, van Wissen, 1995). There are often far fewer pages that refer to the existence of bones in museum collections which preserve tangible remains available for study. There are notable exceptions, such as the significant monograph by Claessens *et al.* (2015), and recent work by Angst *et al.* on museum specimens (2017) that demonstrated what is possible by actually picking up dodo bones and studying them. There are a few publications from curators that highlight their own museum collections, and this article aims to add to notifications of available museum material by Brown (2020) and Fulton (2013).

The dodo skeleton in the NMINH has appeared in simple lists of museum specimens included in a small number of publications (Lydekker, 1891, Fuller 2002) but I am not aware of any

Figure 1. Composite skeleton of a dodo, from 1865 excavations, Mauritius. NMING:F21700.
© National Museum of Ireland.

examination by research visitors of that skeleton, nor any publication since the 19th century of the existence of the rest of the collection in our museum. The details provided here may encourage experts to carry out research on material that seems to have been overlooked.

Dodo remains in Irish collections

The first mention of dodo bones in any Irish collection is by Ball (1853, p.164) who states that Professor Melville (presumably Alexander Gordon Melville, 1819-1901) donated "Casts of the bones of the foot of the dodo" to the Dublin University Museum. Although that remains its official title, the university is better known as Trinity College Dublin (Wyse Jackson, 1992). Its museum in 1853 was based in a building at the front of the College known as Regent House (Figure 2). This specimen cannot be traced, and the phrase 'bones of the foot' may refer to the fully fleshed but dried out foot of the London specimen or could represent the Oxford specimen reduced to foot bones (Joe Parish *pers. comm.* 2012). It is possible that by 1853 both the London foot and the Oxford foot had been skeletonised and cast. The last mention of the London foot with soft tissue was *c.*1848 and the next mention in 1896 states that it lacked integuments according to Hume *et al.* (2006).

There was a relatively small population of people from Britain and Ireland in Mauritius in the mid nineteenth century (Rivière, 2006) but of this group of less than 200 'ex patriates' a number of connections with Dublin led to some direct acquisitions by the Museum of the Royal Dublin Society. The RDS Museum register for 1865 (volume NH-02, Figure 3) details one acquisition as:

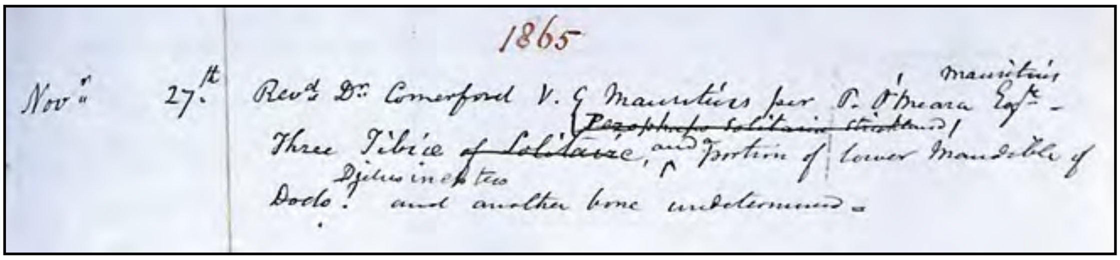
> "Nov. 27th Revd. Dr. Comerford VG Mauritius per P. O'Meara, Mauritius Esq. Three tibiae of Solitaire (*Pezohaps solitaria* Strickland), and a portion of lower mandible of Dodo? *Didus ineptus* and another bone undetermined."

This entry is annotated with some words stricken out "~~*of Solitaire (Pezohaps solitaria Strickland*~~)". It would appear that there was some confusion over the species names to be applied. This is typical of the period, as the status of the dodo as a species and potential confusion with other birds were far from clear and the endemic nature of these species, restricted to single islands was also uncertain (Fuller, 2002). Until a reasonably complete series of bones was illustrated in publication, it was difficult to know which bones were dodo, and what other species might be present in the fossil assemblages.

Figure 2. Print entitled "Museum of T.C.D." a view of the Museum of Trinity College Dublin, in Regent House (over the Front Gate of the college). Drawn and etched by William Benjamin Sarsfield Taylor (1781-1850); Engraved and coloured by R. Havell & Son. Undated (but produced in 1819). (National Museum of Ireland NMINA:16).

The Dr Comerford referred to in the RDS register is Pierce Michael Comerford (1818-1905), born in Coolgreany, Co. Kilkenny and ordained as a Roman Catholic priest in Mauritius in 1845. He rose to hold the position of Vicar General (VG) of Mauritius until his return to Ireland in 1876 (Patrick Comerford *pers comm.* 2012, who certified the first name as Pierce, not Peter as it appears in the *Mauritius Almanac*). Dr Comerford is listed under the entry for the Roman Catholic Church in the *Mauritius Almanac* (Anon., 1864, p.27) as "Vicar -General: Comerford, Dr Peter Michael, £460 per ann." and again few years later (Kyshe 1870, p.312) as "Vicar General – Very Revd. P. M. Comerford, D.D., 300*l* per annum, and 50*l* horse allowance. Appointed March 1845. Is in charge of Diocese. Present salary is 510*l*."

On 1 March 1866 some dodo bones were displayed at a meeting of the Natural History Society of Dublin (Wright, 1866). The dodo bones belonged to Dr Charles Henry Leet (1836-1907) of the 13th Light Infantry regiment, also known as First Somersetshire or Prince Albert's Regiment (Carter, 1867). Leet was not present at the meeting due to ill health (suggesting he was stationed in Dublin, or at least in Ireland, at the time and simply unavailable). Wright mentions that Leet had local knowledge of Mauritius, which indicates that he had at least visited the island and was not just a collector acquiring specimens from a distance. The second battalion of Leet's regiment was based in Mauritius from 1863 and was still stationed there in 1866 (Carter, 1867, pp.171, 179). Their regimental depot in Ireland was


1865

Novr 27th Revd Dr Comerford V.G. Mauritius per P. O'Meara Esqr – Mauritius

~~Pezophaps solitarius Strickland~~

Three Tibiae of Solitaire, and portion of lower mandible of Didus ineptus Dodo! and another bone undetermined –

Figure 3. Entry in the Royal Dublin Society museum register for 27 November 1865. © National Museum of Ireland.

initially headquartered at Fermoy, Co. Cork, then in 1865 it moved to Templemore Co. Tipperary, and later that year to Newry, Co. Down. Officers presumably would have had the freedom to attend scientific meetings in Dublin as is indicated by Leet's absence being due to illness, not being overseas or other causes. If he had been present, more detail might have emerged as to the source of his collection. Leet is noted as a graduate of the University of Glasgow, qualified as a Doctor of Medicine and Master of Surgery in 1834. His entry in a college directory (Addison, 1898) details Leet as "Dublin Professor of (1) Medical Jurisprudence, (2) Materia Medica, in Apothecaries' Hall Medical School; Rathmines, County Dublin; died 2nd May, 1890, aged 89."

The significance of part of Leet's regiment being stationed in Mauritius from 1863 to at least 1866 is that the year 1865 marks the date of the discovery of dodo bones on the island. As a surgeon, Leet would have had an understandable interest in such scientific matters and would not have been alone in acquiring objects of natural history and bringing them to the attention of full time scientists when back home in Ireland. The scientist displaying the bones on the night in 1866 was Edward Perceval Wright (1834-1910), a surgeon, naturalist and Director of the Museum in Trinity College from 1857, later Lecturer in Zoology in the college and then of Botany in Dr Steeven's Hospital Medical School (Dixon, 1910). The bones acquired by Leet and displayed at the Dublin meeting in 1866 comprised "…the larger half of the pelvis, which was very light, weighing only 1 ½ oz., [42.5 g] through the whole of the air cells were filled with dry mud; of a right femur, of two right tibiae, and a left metatarsus…" (Wright, 1866). These were described by Wright as having come from the Mare aux Songes. The pelvis was noted to be slightly asymmetrical, the left side being slightly larger than the right, something Wright considered was due to compression in the mud after burial. The bones in the RDS Museum acquired from Comerford were also displayed at the meeting as a loan from the RDS Curator Dr Alexander Carte, and described as "…more or less perfect specimens of three left tibiae and a small fragment of the left lower jaw" (Wright, 1866).

The dodo skeleton in the National Museum of Ireland

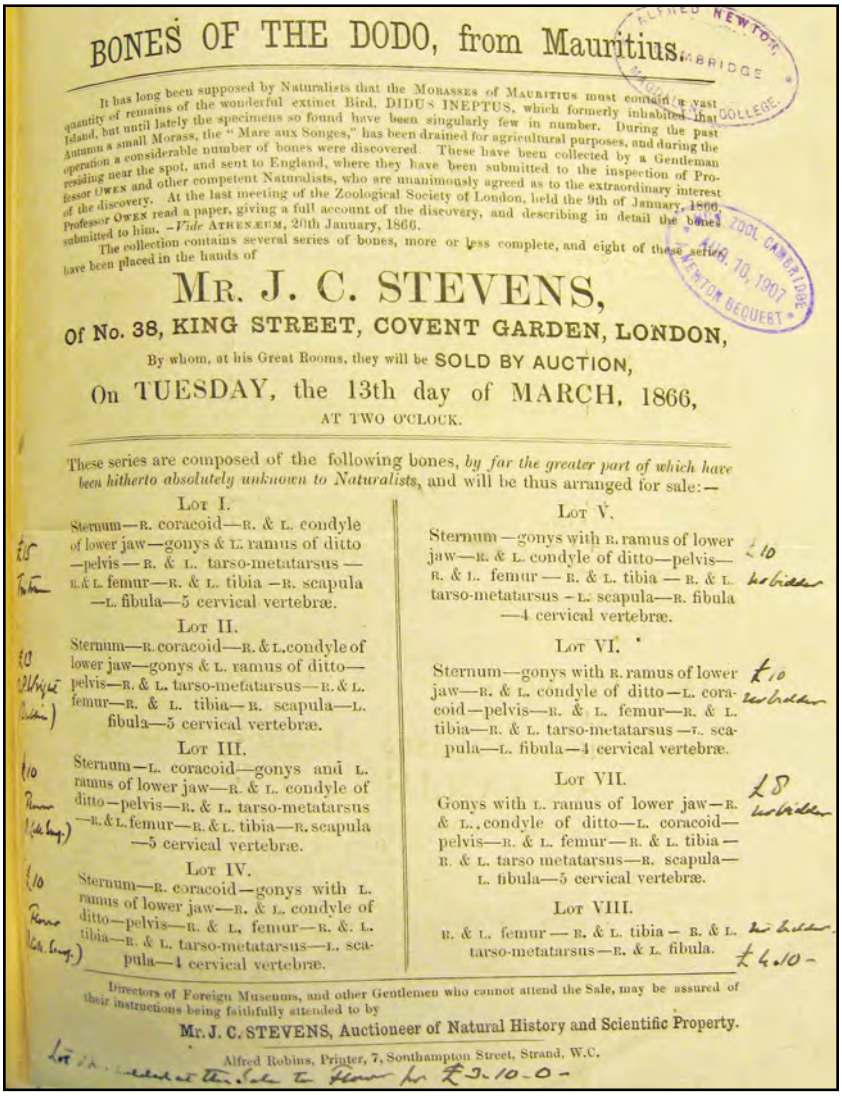
Less than a fortnight after the display of dodo bones by Wright in Dublin there was an auction in London of considerable significance. In the auction rooms of Mr J. C. Stevens on Tuesday 13 March 1866 several sets of dodo bones were available in a total of eight lots. In the copy of the sale catalogue in the University of Cambridge there are annotations showing the fate of these lots (Figure 4). Lot number two is marked as: "£13 E.P. Wright (Dublin)". The entry in Stevens' catalogue for the sale describes this lot as:

LOT II.
Sternum – R. coracoid – R. & L. condyle of lower jaw – gonys & L. ramus of ditto – pelvis – R. & L. tarso-metatarsus – R. & L. femur – R. & L. tibia – R. scapula – L. fibula – 5 cervical vertebræ.

This amounted to a sternum (breastbone), right coracoid, right and left condyle of lower jaw, gonys (the ridge on the lower mandible from the tip to where the two sides of the jaw or 'rami' branch) and left ramus of ditto (*i.e.* left side of lower jaw), pelvis, right and left tarso-metatarsus, right and left femur, right and left tibia, right scapula, left fibula and five cervical vertebrae. This compares well with the composite skeleton in Dublin today but that skeleton also has an almost complete set of vertebrae, ribs, with plaster toes and skull.

One of the lots at auction is noted as purchased by the British Museum and two others going to the Royal College of Surgeons at £10 per lot. According to the annotated catalogue in Cambridge there were no bidders for the remaining four lots at the auction, at £10, £10, £8 and £4-10-0 respectively. All lots were similar in completeness to the lot purchased by Wright, apart from the final lot which comprised only 8 leg bones.

Wright's interests in natural history were many and varied. In 1865 he had become particularly involved in vertebrate palaeontology. A chance discovery of important amphibian fossils in an Irish coal mine led to collaboration with Thomas Henry Huxley (1825-1895) and a flurry of correspondence between Wright in Dublin and Huxley in London (DeArce, *et al.* 2011). The timing of the display of Leet's dodo bones in Dublin may have been stimulated by the advance notice of the Steven's sale and the opportunity that could provide to acquire enough bones to reconstruct a dodo skeleton. It may also have been necessary to enthuse the RDS to support a significant purchase. Wright sat on the Natural History Committee of the RDS, which looked after the construction of the museum building, major purchases, and invoices (Monaghan, 2021a). He would have been a logical choice to represent the RDS in acquiring a dodo skeleton.



BONES OF THE DODO, from Mauritius.

It has long been supposed by Naturalists that the MORASSES of MAURITIUS must contain a vast quantity of remains of the wonderful extinct Bird, DIDUS INEPTUS, which formerly inhabited that Island, but until lately the specimens so found have been singularly few in number. During the past Autumn a small Morass, the "Mare aux Songes," has been drained for agricultural purposes, and during the operation a considerable number of bones were discovered. These have been collected by a Gentleman residing near the spot, and sent to England, where they have been submitted to the inspection of Professor OWEN and other competent Naturalists, who are unanimously agreed as to the extraordinary interest of the discovery. At the last meeting of the Zoological Society of London, held the 9th of January, 1866, Professor OWEN read a paper, giving a full account of the discovery, and describing in detail the bones submitted to him. –*Vide* ATHENÆUM, 20th January, 1866.

The collection contains several series of bones, more or less complete, and eight of these series have been placed in the hands of

MR. J. C. STEVENS,

Of No. 38, KING STREET, COVENT GARDEN, LONDON,

By whom, at his Great Rooms, they will be SOLD BY AUCTION,

On TUESDAY, the 13th day of MARCH, 1866,

AT TWO O'CLOCK.

These series are composed of the following bones, *by far the greater part of which have been hitherto absolutely unknown to Naturalists*, and will be thus arranged for sale:—

LOT I.
Sternum—R. coracoid—R. & L. condyle of lower jaw—gonys & L. ramus of ditto—pelvis—R. & L. tarso-metatarsus—R. & L. femur—R. & L. tibia—R. scapula—L. fibula—5 cervical vertebræ.

LOT II.
Sternum—R. coracoid—R. & L. condyle of lower jaw—gonys & L. ramus of ditto—pelvis—R. & L. tarso-metatarsus—R. & L. femur—R. & L. tibia—R. scapula—L. fibula—5 cervical vertebræ.

LOT III.
Sternum—L. coracoid—gonys and L. ramus of lower jaw—R. & L. condyle of ditto—pelvis—R. & L. tarso-metatarsus—R. & L. femur—R. & L. tibia—R. scapula—5 cervical vertebræ.

LOT IV.
Sternum—R. coracoid—gonys with L. ramus of lower jaw—R. & L. condyle of ditto—pelvis—R. & L. femur—R. & L. tibia—R. & L. tarso-metatarsus—L. scapula—4 cervical vertebræ.

LOT V.
Sternum—gonys with R. ramus of lower jaw—R. & L. condyle of ditto—pelvis—R. & L. femur—R. & L. tibia—R. & L. tarso-metatarsus—L. scapula—R. fibula—4 cervical vertebræ.

LOT VI.
Sternum—gonys with R. ramus of lower jaw—R. & L. condyle of ditto—L. coracoid—pelvis—R. & L. femur—R. & L. tibia—R. & L. tarso-metatarsus—L. scapula—L. fibula—4 cervical vertebræ.

LOT VII.
Gonys with L. ramus of lower jaw—R. & L. condyle of ditto—L. coracoid—pelvis—R. & L. femur—R. & L. tibia—R. & L. tarso metatarsus—R. scapula—L. fibula—5 cervical vertebræ.

LOT VIII.
R. & L. femur—R. & L. tibia—R. & L. tarso-metatarsus—R. & L. fibula.

Directors of Foreign Museums, and other Gentlemen who cannot attend the Sale, may be assured of their instructions being faithfully attended to by

Mr. J. C. STEVENS, Auctioneer of Natural History and Scientific Property.

Alfred Robins, Printer, 7, Southampton Street, Strand, W.C.

Figure 4. Catalogue of dodo lots available at auction by Mr J. C. Stevens on Tuesday 13 March 1866, note marginal annotation on extreme left for Lot II "£10 E.P. Wright, Dublin" (University of Cambridge, courtesy of J. Parish).

The Stevens auction catalogue entries indicate collections of bones, rather than mounted skeletons. While Richard Owen had the opportunity to intercept the whole collection and examine it before the sale (Hume *et al.*, 2009), there had not yet been a full skeletal reconstruction illustrated for taxidermists to work from. Owen produced such a reconstruction in October 1866 (Owen, 1866) and revised it in 1872 (Owen, 1872). The posture of the mounted skeleton in the NMINH is much closer to the second illustration. There is no record or label however to indicate where the supplementary bones not purchased at the Stevens auction were sourced, or even if this is definitely the collection purchased by Wright. It is however the most likely, and probably the only possible source of such a complete skeleton.

The lack of a clear trail of provenance includes being unable to trace the ownership of the specimen from Wright's purchase to the dodo skeleton being in the RDS Museum. The RDS catalogue system did not employ register numbers and relied on a handwritten accession register series commenced in 1834, and labels accompanying individual specimens. There is no entry for any dodo material apart from the small number of bones detailed above that were received from Dr Comerford. There are no old labels with the skeleton, and more recent labels show no acquisition details. The quality of recording of acquisitions in the RDS Museum was often far from detailed and frequently very unsatisfactory, with separate registers for donations and for purchases. It is still very surprising that there is no mention of such a significant specimen in the purchases registers for 1866-1867. Labels accompanying specimens normally stressed the donors, who were usually RDS members or notable personages. It was normal practice however, never to refer to vendors, so the names of commercial supply companies, taxidermists or others engaged in trade were never included.

Wright was an important member of the RDS Natural History Committee (NHC). Their manuscript minute books are preserved for the years 1831-1877 and report sanctions for expenditure. Sums of the order of £10 would normally appear, although sometimes larger amounts were simply recorded as owing to the curator for various items, without specifics. Wright made at least one trip on behalf of the RDS to London in 1852, where he was purchasing specimens for the RDS collections (RDS Minute book 302977, entry for 9 February 1858). It is most likely that the bones were acquired by Wright at the Stevens auction on behalf of the RDS. It is not impossible that the collection of dodo bones may have been purchased by Wright for his personal collection or for the Trinity College museum but the development of the RDS Museum at the time and its high levels of spending on acquisitions for its new building make it much more likely to be a direct RDS acquisition.

The answer to the missing payment lies in an entry in the minute book of the Natural History Committee of the RDS for 15 February 1867. It simply records a payment of £15 to "Mr Banks, for dodo's bones" without any further detail. This transaction is not recorded in the RDS Museum volume of purchases for 1866-1872 (volume NH-03). The amount noted as paid by Wright at auction is £13, so it is possible that this is the payment, plus £2 for packing and carriage. However, later transactions with Stevens for other museum acquisitions have invoices and payments direct to Stevens. The surname could link to Mr W.T. Banks, a collaborator with George Clark in Mauritius, indicating payment direct to the source, rather than the auctioneer. W. T. Banks had a posthumous connection to Dublin in that his widow Helena Rebecca Banks married Christopher J. Guy Carleton in Kingstown (now Dun Laoghaire) on 3 May 1877.

If by a slim chance, the dodo bones from Stevens were bought by Wright for Trinity College, they could have been transferred subsequently to the RDS Museum. Significant collections from the TCD museum were transferred to the RDS once the latter constructed a dedicated museum building in 1856 (Monaghan, 2007). When the ground floor of the RDS Museum was fitted out in 1864, a collection 150 plaster casts of record specimen Irish fish was given by the Board of Trinity College, indicating that some significant specimens were transferred at that time. Further significant vertebrate palaeontology collections (Lydekker, 1884), and ethnographic collections (Hand, 2012) were also transferred from TCD. These occurred after the state took over the running of the RDS Museum in 1877 and worked towards construction of another major museum in an adjacent building that opened in 1890 (O'Riordan, 1983).

The link between the auction and the bones in the RDS Museum is strong but circumstantial, however the source of the bones auctioned at the sale by Stevens is much clearer and is detailed by Hume *et al.* (2009). While there were many Mauritian residents on the hunt for dodo remains, and small numbers of bones made it out from as early as 1860 through a variety of connections to people such as Dr Comerford and Dr Leet, the majority of bones in museums today came through efforts of a local schoolmaster George Clark. Bones sufficient to comprise two fairly complete composite skeletons were sent by Clarke to England, one consignment direct to Richard Owen, and a second set despatched separately via Edward Newton in Mauritius to his brother Alfred Newton in the University of Cambridge. These latter bones were intercepted by Owen and not released to Newton until after Owen had the opportunity to study and publish the full collection. Further collections went to Stevens for auction, but all of these appear to have passed first through the hands of Owen. Newton didn't have access to the British Museum bones, but did see all of Stevens' lots before the auction. These two comparative anatomists competed to be the first to publish the finds, with enduring acrimonious results (Hume *et al.*, 2009).

The bones listed in the Stevens auction catalogue were all from the fieldwork of George Clark in 1865. The detailed story is given by Hume *et al.* (2009) and outlines the reality of the 'excavations' at the Mare aux Songes. This was a swamp where local labourers waded with safety ropes tucked under their armpits, picking up bones by feel, scooped from the waterlogged sediment using their hands and feet (Clark, 1866). With such recovery techniques, it would have been well-nigh impossible to maintain any associations between related skeletons. The sorting of bones into Stevens' discrete auction lots with groups of comparable size must have been the work of Owen or possibly Alfred Newton.

In 1870 the collection of dodo bones in the Museum of the RDS had not yet been mounted but the makings of a decent skeleton were in the collections. In the archives of the National Muse-um of Ireland three letters survive that give some insight into the arrangements for the mounting of the dodo composite skeleton. This is only one side of the correspondence however, as no copies were made of the outgoing letters from the curator. The letters are all from Edward Gerrard junior (1832-1927) writing from 31 College Place, Camden Town (London NW1). Gerrard was a respected and capable taxidermist from a family business with several 'Edward Gerrards' (Morris, 2004), who supplied the Museum of the RDS with specimens on a regular basis. In 1870-1871 the Museum of the RDS paid Gerrard a total of £355-18-6 for various specimens (Table 1). These are not all detailed in the records that have been traced, but presumably one of these payments includes the costs of mounting of the dodo skeleton.

The letters from Gerrard are all addressed to Dr Alexander Carte MD TCD, FRCSI, FRS (6/8/1805-25/9/1881), then Director of the Museum of the RDS (Figure 5). Carte worked at the Museum of the Royal College of Surgeons in Dublin from 1846. In 1851 he was elected 'Curator' of the Museum of RDS, a title later changed to 'Director' (Praeger, 1949). When the state took over the running of the RDS Museum on 14 August 1877, Carte was confirmed as 'Director of the Natural History Museum' on a personal basis, as there was also a 'Director of the State Institutions of Science and Art' who was his superior in charge of the Museum of Science & Art, Dublin. Carte served in the Museum of Science & Art until his death, after which the post was entitled 'Keeper'. He published research in various areas of zoology and was at the centre of an extended scientific network (Murphy, 2015; 2021).The museum was later renamed the National Museum of Ireland (O'Riordan, 1983).

On 24 November 1870 Gerrard replies to Carte, referring to his earlier letter. Amongst paragraphs on other specimens, he gives a brief summary of the dodo bones that are by now in London:

"In answer to your letter about the Dodo I think I have all the required bones except the ribs, but they are not of much consequence. I could model them up. The Museum specimen has only a few and they are fixed to the vertebra. Prof. Owen has left today for Egypt where I believe he intends to stay for 2 months. So I suppose nothing can be done until his return."

Table 1. RDS Museum payments to E. Gerrard in 1870-1871 recorded in National Museum of Ireland – Natural History register volume number NH-03 labelled "1866-1872 Purchases". Dates are not always given and where they are detailed, it appears to be a mid-month date, suggesting that reporting requirements were based around monthly accounts. Information inferred by the author is in [square brackets]. The currency is Pounds-Shillings-Pence Sterling.

Date	Details	Payment
18 February 1870	Fish from Indian Ocean	£9-0-0
18 March 1870	Skins of Mammals	£25-0-0
1870 [between March-October]	Birds and Mammalia and other specimens	£16-4-6
1870 [between March-October]	skins	£36-15-0
1870 [between March-October]	[No details]	£29-4-0
1870 [between March-October]	Mammalia	£25-0-0
17 February 1871	Collection of fish from Mysol [an island in the Ceram Sea, between Indonesia and Papua New Guinea]	£10-10-0
19 May 1871	Skins of Mammalia including Lemur rubra male and female, Eupleres goudotii and others from Madagascar, Ailurus fulgens etc. and 203 specimens of South American birds authenticated by Mr O. Salvin. A number of other Bird's skins etc.	£73-11-6
1871	[No details]	£32-0-0
September 1871 [or later that year]	Skins of mammals and birds	£66-4-6
September 1871 [or later that year]	Skins of mammals and birds	£14-9-0

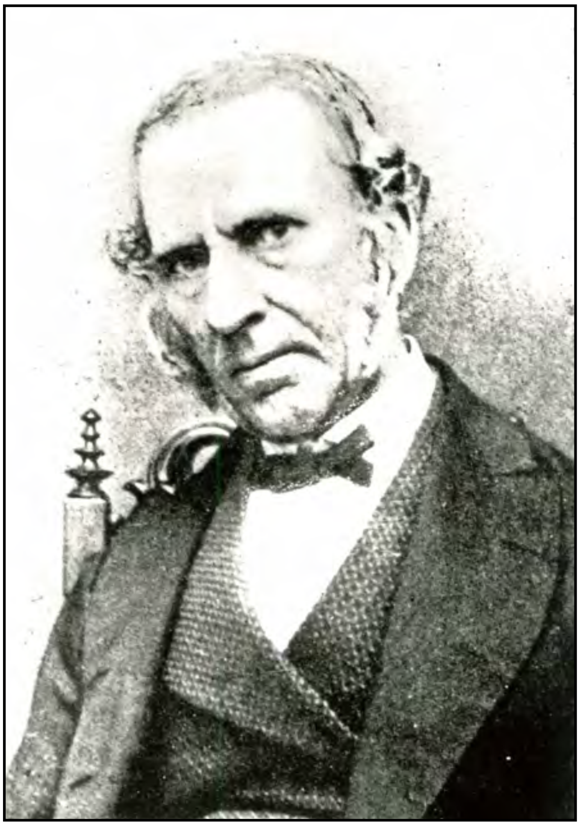


Figure 5. Dr Alexander Carte (1805-1881), Director of the Museum of the RDS.

Professor Richard Owen (1804-1892) was appointed in 1856 as Superintendent at the British Museum to manage the natural history departments. Access to any dodo specimens under his control would not have been the simplest thing to achieve based on what is documented about his relationships with any scientist who could be considered a competitor (Hume *et al.* 2009). In this case however, it should have been possible for another respected museum curator such as Carte to arrange mere copies of bones to complete a skeleton, but presumably not something that Gerrard would consider being able to do himself.

A letter to Carte from George Robert Gray (1808-1872), head of the ornithological section of the British Museum, includes a polite refusal of casts of dodo bones.

"British Museum
15 Dec 1870

Dear Sir
I have, in answer to your letter of 12th, to inform you that it is, I regret much to say, out of my power to assist in supplying you with those parts you require to complete the skeleton of the Dodo that you are so anxious to set up for exhibition. All the parts, you ask for, are fixed to our skeleton and it is impossible [to] separate them without injury to the specimen.

I think that Mr Moore of the Free Library and Museum Liverpool could assist you as I understand that he has many bones of the Dodo, which are not set up and therefore might be more easily modelled in plaster.
With Compliments of the coming season I remain
Truly Yours

G. R. Gray"

Thomas John Moore (1824-1892) was curator of the Liverpool Museum for 40 years, with particular interests in zoology and comparative anatomy (Anon., 1892). The collection in what is now known as World Museum Liverpool (LIVCM numbers 1984.1440 and 1984.1441) was a gift from Harry Pasley Higginson, that arrived in February 1866 (Wilson ,2020). Higginson was an important figure in collection of dodo bones in Mauritius (Brown, 2020), and the Liverpool gift was part of a wider distribution of bones to the museums of York and Leeds. The museum in Liverpool also received a smaller set of bones (numbered LIVCM 26.9.67.1-14) from engineer Walmsley Stanley in 1867 (Wilson, 2020). By the time of receipt of Gray's letter there would appear to have been no need to contact Moore as only ribs remained to be sourced.

On 12 April 1871, Gerrard contacts Carte again, in a letter annotated by Carte as having been answered on 18 April 1871. Between notes of collections of skins sent to Dublin on approval is this encouragement to get the absent bones supplied as casts from the British Museum collection:

"I think if you was to write to Profr. Owen for the Dodo's vertebra he might be likely to have the casts made. Have you succeeded in getting a cast of the skull, if not shall I try?"

Gerrard's letter of 10 June 1871 indicates that he had resolved his need to obtain casts of absent vertebrae, and had modelled the other missing parts. He doesn't detail whether Gray's suggestion to approach Moore in Liverpool was part of resolving the issue and no records have been found in Liverpool relating to this (John Wilson pers. comm. 10 May 2021). Carte had obtained a cast of a skull from the specimen in Copenhagen allowing the skeleton to be completed. The RDS Museum register entry (NMINH volume NH-02 for 1871) reads: "April 25 Professor Iapetus Steenstrup, Kőbenjavn. A cast in plaster of the Dodo's skull from the University Museum of

Copenhagen." With sufficient material now assembled, Gerrard was able to write to Carte:

"I have sent off a box containing the Dodo skeleton, which I hope will arrive safely.
I have put it up so that every bone can be taken apart for examination.
I think you will be able to put it up easily.
The femur has a piece of wire sticking out which goes into the hole at the top of the tibia and the same from the tibia into the tarsus. The piece of twisted wire at the side of the tibia goes into the cross piece and the upright.
I think it can be quickly put up from the rough sketch on the other side."

The sketch included in the letter is shown here (Figure 6) and matches the posture of the specimen now in Dublin. Owen published a posture very similar to this in 1872 and it is possible that Gerrard had advice from Owen, or sight of drawings showing these intentions. It is worth noting that Gerrard's father (Edward Gerrard senior) worked as a taxidermist and mounter of skeletons for Owen (Morris, 2004).

The specimen impressed Dr Ferdinand Roemer, Professor of Mineralogy in the University of Breslau on his visit in 1876 (Roemer, 1878):

"The specimen of Didus ineptus, complete all but the skull, which has been artificially supplied, is likewise exceedingly interesting. Numerous remains of this extinct bird were found a few years ago in draining a swamp in the island of Mauritius; an event which makes the conjecture probable that, in the course of time, several more specimens of this singular bird may be brought to Europe."

Dodo specimens in the National Museum of Ireland today

The vertebrate palaeontology collections of NMINH were published in a catalogue (Lydekker, 1891) that was part of a series, based on employment of experts in various collections, who had produced catalogues for the British Museum and were brought to Dublin at state expense. It is important to understand that at that time, Ireland was a constituent part of the UK and the museum in Dublin reported into the Department of Science & Art, based in South Kensington, London.

Richard Lydekker's catalogue entry for dodo specimens in Dublin (1891, p. 41) reads as follows:

Suborder Columbae
Family Dididae
Didus ineptus
Linn., Syst. Nat., ed. 12, vol. I, p. 267 (1766).
From Marshes in the Island of Mauritius.

a. The skeleton, partly restored, and made up from the bones of more than one individual.
b. Cast of the skull.
c. The cranial rostrum.
d. A series of limb-bones and vertebrae; from Mahbourd, Mauritius. *Presented by Rev. Dr. Comerford, 1865*

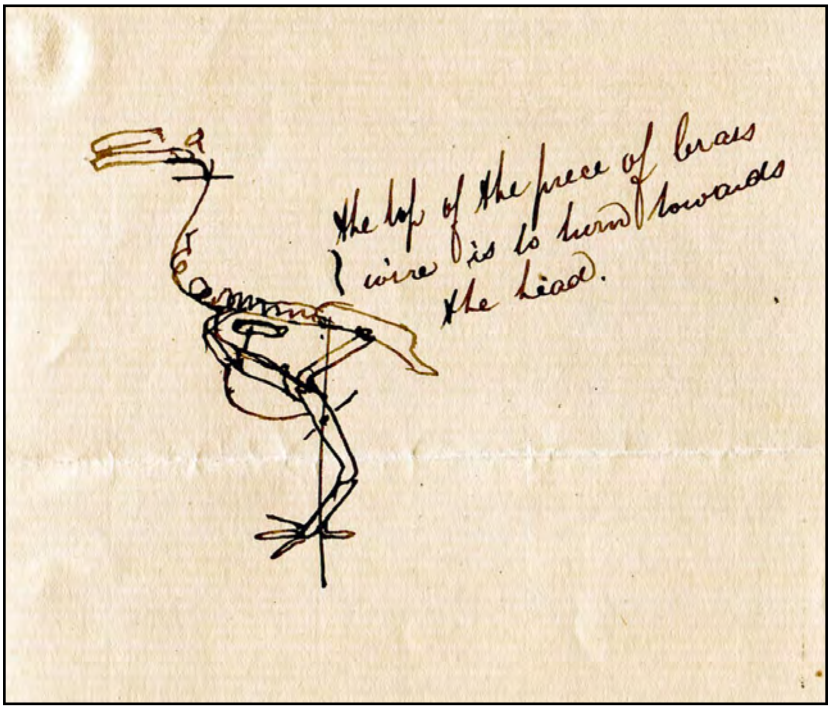


Figure 6. Sketch of the Dublin dodo skeleton by Edward Gerrard junior, in letter of 10 June 1871. With text "The top of the piece of brass wire is to turn towards the head"

Unfortunately although register numbers were introduced from 1877 in what is now the National Museum of Ireland, they were only applied to new acquisitions, with no systematic retrospective numbering of RDS collections until 1981. Neither Lydekker as author of the catalogue, nor the curator who succeeded Carte, labelled specimens with letters matching the published catalogue entries and any connections below are inferred. Numbers below are all from retrospective catalogue exercises, with those applied to original dodo bones coming from the series applied to fossils in the geological collections from 1981 onward (series NMING:F).

Table 2. Catalogue of dodo specimens in the National Museum of Ireland - Natural History.

NMING:F21733 Left tibia Original bone, labelled Rev Dr Comerford V.G., Mahbourd, Mauritius. This is presumably Mahebourg, near the classic 1865 dodo locality of Mare aux Songes.	
NMING:F21734 Left tibia, broken in three Original bone, labelled Rev Dr Comerford V.G., Mahbourd, Mauritius	
NMING:F23414 Original bone, labelled Rev Dr Comerford V.G., Mahbourd, Mauritius	

Table 2 (Cont.) Catalogue of dodo specimens in the National Museum of Ireland - Natural History.

NMING:F23415 Left tibia Original bone, labelled Rev Dr Comerford V.G., Mahbourd, Mauritius	
NMING:F21735 Rostrum of skull Presumably the 'cranial rostrum' of Lydekker 1891	
NMING:F23416-F23418 Three ribs	
NMING:F21739 Fragment of mandible Original bone, labelled Rev Dr Comerford V.G., Mahbourd, Mauritius The "small fragment of the left lower jaw" referred to by Wright 1866.	

Table 2 (Cont.) Catalogue of dodo specimens in the National Museum of Ireland - Natural History.

NMING:F21740 Cervical vertebra	
NMING:F21741 Cervical vertebra	
NMING:F21742 Cervical vertebra, with string binding	
NMING:F21743 Left scapula	

Table 2 (Cont.) Catalogue of dodo specimens in the National Museum of Ireland - Natural History.

NMING:F21745 Plaster replica of the Copenhagen skull. Probably the original acquired by RDS 25 April 1871 from Professor Iapetus Steenstrup, Copenhagen and later damaged and replaced on the skeleton by a second copy. Based on the specimen now in the Zoological Museum of the University of Copenhagen ZMUC 105.485	
NMING:F21744 Plaster replica mandible, broken and repaired.	
NMINH:2006.12.1703 Plaster replica of the head of the dodo based on that preserved in Oxford University Museum. This is inscribed on the base of the neck in a style that appears to have been written into the wet plaster: "J. Johnson M ... [possibly 'made in' but words obliterated by a later hole that is probably for mounting] Oxford". Presumably this relates to the request by J. Johnson for five casts from the Oxford University Museum in 1837 (Nowak-Kemp and Hume, 2016, Mark Carnall *pers comm.* 2016).	
NMINH:2006.12.1703 Base of the neck showing inscription.	

Table 2 (Cont.) Catalogue of dodo specimens in the National Museum of Ireland - Natural History.

NMINH:2008.73.457 Unpainted and chipped plaster replica of the foot of the dodo based on that preserved in the Natural History Museum, London (NHMUK). The original is now lost, or possibly dissected and the skin discarded (Hume *et al.,* 2006).	

Conclusions

The composite skeleton and small number of individual dodo bones and casts that are now in the National Museum of Ireland in Dublin are an important resource. While the skeleton has been on display for well over a century, it does not appear to have been studied in detail. It is off display as part of the decant of collections in advance of major roof works (Monaghan, 2021b). Now that the research has been done on the provenance of the specimens, it would be a good opportunity for experts to examine the collection so that a future exhibition would benefit from a greater understanding of one of Dublin's most important fossils.

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I am indebted to Dr Joe Parish for the information on the annotated copy of the Stevens auction catalogue, and Dr Rachel Hand for drawing my attention to relevant records in our own museum archives. Mark Carnall of the Oxford University Museum provided information on the plaster casts made from their dodo head. Dr Jan Bolding Kristensen of the Natural History Museum of Denmark provided details of the Copenhagen skull. Dr Patrick Comerford supplied biographical information on his ancestor Dr Pierce Comerford. Bruce Carte supplied family and career details for his ancestor Alexander Carte. Curators Dr Patrick Wyse Jackson (geology) and Dr Martyn Linnie (zoology) in Trinity College Dublin searched for dodo information in their collections and archives, sadly without success. Dr John Wilson of National Museums Liverpool checked for correspondence from Dublin. Paolo Viscardi, National Museum of Ireland gave useful advice on the manuscript prior to submission. Two anonymous reviewers provided valuable feedback and additional information.

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Losing colour: the discolouration of plants in spirit preserved collections

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Abstract

The Research unit of the Haute-École Arc Conservation-Restauration (UR-arc CR), Neuchâtel, Switzerland, is carrying out a research project that aims to understand the discolouration of botanical spirit preserved collections and strives to propose practical solutions to these problems. This article reports on the results of the initial phase of this project, which focused on creating experiment jars of representative plants specimens immersed in fluids and monitored using the following protocol: photography of the jars, colorimetric measurements, and analysis by UV spectroscopy of the fluid as well as closer observations of the specimens. Colorimetric measurements tracked the colour changes over time. UV spectroscopy was used to identify the pigments present in the fluid. Thereby, different behaviours could be observed, depending both on the type of pigment and on the fluid. Specimens containing pigments with strong dying properties tend to opacify the fluid while keeping their colour, whereas other specimens such as colourful flowers or leaves show clear discolouration problems. Depending on the preservative fluid, the leached pigments degrade at different rates. Moreover, the botanical specimens show other alterations: they may not only assume a lighter or darker colour, but can also shrink, stiffen or soften.

Keywords: Spirit preserved collections, plants, fluid preserved, botany, discolouration, spectrocolorimetry, UV-Vis spectroscopy

Introduction

In botany, besides living plants in gardens or greenhouses, specimens are usually dried and pressed in herbaria. However, they can be preserved in other media, to keep or enhance some of their features. For significance (e.g., Guntau, 1996), expressions of nationalistic pride (e.g., Vogel, 2015), and instruments of both formal and public education. Those values have guided how minerals have been collected, organised, and displayed (Kohlstedt and Brinkman, 2004).

For instance, the "fresh" aspect of a plant as well as its structure and spatial placement can be better preserved if stored in fluid. Similarly, if displaying the specimen is not required, keeping it in frozen storage assures the preservation of its genetic material, which often degrades when pressed or preserved in fluid (Williams, *et al.*, 1999).

Fluid preservation, also called wet preservation, is a technique that dates back to the 17th century. It was then mostly used on animal or human specimens for biological, medical, pathological or curiosity collections. For botanical collections however, the practice developed later (early 19th century) and was less common (Moore, 2010). The process can vary but follows generally the same steps described in Figure 1. The specimen is first collected and cleaned. The preparation for storage can include a fixation step, where the specimen is immerged for some time (from a few hours to a few days generally) in an aqueous solution containing a fixative agent. Depending on the specimen and the display concept, it might also be given a special mounting. Finally, it is put in a sealed container filled with a transparent preservative fluid to be stored or displayed. It will not be removed from this fluid except for some studies, analyses, or restoration interventions.

According to a review carried out across Europe, most of the botanical museums and herbaria store their collections in 70% Industrial Methylated Spirit (IMS) or ethanol, sometimes with previous fixation, either with a solution of ~4% formaldehyde or a commercial preparation of Formaldehyde - Acetic acid - Alcohol (FAA), and sometimes with ~1-5% added glycerol. Some other preservatives often used are Kew mixture, Copenhagen solution, Rum 60° or formaldehyde solution (Prakash, 2019). There are several versions of Kew mixture and Copenhagen solution that have been developed,

Figure 1. Preparation of wet specimen from the collect, through the fluid preservation process, to the cycle of interventions once part of the collection. © UR-Arc CR 2021.

refer to Simmons (2014) and Moore (2010) for details of fluid mixture compositions.

The botanical wet collections are known to be subject to issues related to the presence of vegetal pigments in their specimens. On one hand, the loss of colour in the specimen can go as far as total whitening of the tissues, especially for leaves and flowers. On the other hand, the colouring of the fluid can sometimes lead to an excessive opacification of the jar, especially for darker and pigment-rich specimens. This can occur in both water-based and alcohol-based fluid preservatives, as the pigments or dyes present in the specimens are solubilised by the preservative fluid.

The study presented in this paper is carried out in collaboration with the Botanical Museum of Zurich University and the botanical garden of Neuchâtel and aims at understanding the sensitivity to discolouration of different types of specimens that have undergone various preparation processes. Based on these initial observations, recipes for the targeted preservation of certain pigments (i.e. chlorophylls, flavonoids, betalains, carotenoids and phenolic tannins) will be sought in further steps of the project.

Methods

Preparation of the experiment-jars

A series of tests were carried out within the framework of this study, consisting of several sets of experimental jars that were designed to observe specific aspects of the studied problem. The varying parameters were: the type of specimen and the pigment expected to be leaching, the impact of the fixative used and of the preservative fluid chosen.

Fresh specimens representing different plant types or organs, listed in Table 1, were chosen according to their availability and seasonality. Most of them could be acquired, thanks to the Botanical Garden of Neuchâtel. Set 1 contains leafy specimens, flowers, and fruits with brighter colours knows to show discolouration issues in collections. Set 2 contains more pigment-rich specimens known for their dying properties and often subject to fluid opacification in wet collections.

The preparations chosen, listed in Table 2, were designed to simulate different possible situations observed in collections. Fixation is not always a necessary step in the preparation process. If included, botanical specimens are usually immersed in formaldehyde solution or FAA baths for approximately 24 hours before being

Table 1. Specimens selected, detailing the colour and main pigment expected to leach into the fluid.

Specimen	Type / Organ	Colour	Main pigments of interest	set
Lavender	Stalk with flowers	Green / purple	Chlorophylls +anthocyanin flavonoids	1
Mint	Stalk with leaves	Green	Chlorophylls	
Chili pepper	Fruit	Red	Carotenoids	
Beetroot	Root - cut	Purple	Betalains	2
Fresh walnuts	Fruit - cut	Green / brown	Chlorophylls + Phenolic tannins	
Dried walnuts	Fruit - cut	Brown	Phenolic tannins	

transferred into the preservative fluid (Moore, 2010). A 4% w/v formaldehyde solution buffered pH 6,9 (Merck KGaA) and a commercial FAA histological fixative containing (v/v) 40-50% ethanol, 10-15% formaldehyde, 5-10% acetic acid and 3-5% methanol (VWR™ chemicals) were selected for this study. A condition assessment carried out on collections of the Botanical Museum of Zurich University showed that some specimens were preserved in formaldehyde solutions for many years (Dangeon, 2016). Therefore, 4% w/v formaldehyde solution was also used as preservative fluid on some test specimens.

A solution of 70% v/v ethanol made from absolute ethanol (VWR™ chemicals) and demineralized water was selected. Ethanol or IMS are the main preservatives used in museums, but commercial rum is sometimes used as a substitute, either as a temporary "on field" solution or permanent preservative (Grant, 2019). Bacardi® White Rum (37.5% vol alc) was selected.

Finally, glycerol is sometimes added in a small percentage to preserve flexibility of the fixed tissues, especially in collections where the specimen might be manipulated for study. It is less

Table 2. List of preparations combining fixative and preservative. Code of preparation for experimental phase.

Fixative [250ml]	Time	Preservative [350ml]	Code	Comment
No fixation bath		70% Ethanol	OE	Main preservative fluid used in museums
4% w/v formaldehyde solution	24h		FE	Fixative the most used in museums
FAA	24h		AE	Commercial fixative broadly used for botanical specimen
No fix. White Rum	7 d		OR_E	Temporary storage with readily accessible alcohol during "on field" campaign
No fixation bath		White Rum (37.5% alcohol)	OR	Used as alternative preservative or as temporary "on field" solution.
No fixation bath		4% formaldehyde solution	OF	Formaldehyde solution used as preservative fluid
FAA	24h		AF	
No fixation bath		70% Glycerol	OG	Less hazardous preservative fluid
4% formaldehyde solution	24h		FG	
FAA	24h		AG	

hazardous than formaldehyde and ethanol both for people and storage, and it has also been used as a preservative fluid (Van Dam, 2018). In this study, glycerol (VWR™ chemicals) was selected, with a 70% concentration in demineralized water.

Specimens were weighed before being immersed in fluid. To ensure a similar volume ratio between the specimen and the fluid in the jars, the beetroots and walnuts had to be cut into smaller parts. The specimens that had to be fixed were first put in a 250ml bath of the chosen solution. Eventually, all specimens were put in glass jars with a closed lid (IKEA® Korken 500ml) filled with 350ml of preservative fluid. The monitoring of these experiments started at T_0, on the day on the preparation, showed in Table 3.

Monitoring protocol

The prepared specimens were stored in the dark in a solvent cabinet with forced air filtration but without climate control, and were monitored frequently for 3 months: daily during the first five days, weekly for the remainder of the first month and every two weeks for the following two months.

The protocol included both visual observation and photography (Canon® EOS 600D – 1/60 F8.0 ISO 100) of the jars in a white lightbox with a reference colour & grey control chart (B.I.G. GmbH) to document the visual changes of the fluid's and specimen's colour through time. To complement this qualitative documentation, the colour of the fluid at each monitoring day was also quantitatively assessed with a portable spectrophotometer (X-rite® Ci62). This instrument acquires the reflectance electromagnetic spectrum, in the visible light range, of an investigated sample. For this project, it was mounted on a vertical stand equipped with a cell for liquid measurements. 6ml of fluid were sampled from the jar with a graduated pipette, three measurements were performed and the average value retained.

From the reflectance spectrum, CIELAB colorimetric values can be extracted. The CIELAB colour space expresses colour as 3 values: *L** represents the lightness scale ranging from 0 (black) to 100 (white); *a** the green-red value from -X (green) to +X (red); *b** the blue-yellow value from -Y (blue) to +Y (yellow). These values are relative to a specific illuminant, defining the white of reference. For this protocol, illuminant D65 (standard day light) was used.

This allows to quantify the fluid's colour change by computing the difference between the colour values in CIELAB space measured on the fresh preservative solution on the day it was prepared (T_0) and the same fluid on the day of the monitoring (T_x). This difference is expressed with Delta-E (ΔE), the Euclidian distance between these two points in the colour space. It is calculated using the following equation, where L_1^*; a_1^*; b_1^* stand for the clean preservative and L_2^*; a_2^*; b_2^* for the fluid at time of measurement.

$$\Delta \mathrm{E} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

(Zuppiroli & Bussac 2012)

ΔE is a strictly positive value, where the two L*a*b* colour values compared are identical if $\Delta E=0$ and diverge as ΔE grows. A colour difference cannot be perceived by the human eyes when Delta E is less than 1 ($\Delta E<1$), and only becomes clearly noticeable around 10. Above this value, the compared colours are perceptibly different (ViewSonic, 2021). In this paper, any colouration of the fluid of Delta E greater than 10 ($\Delta E>10$) will therefore be considered as a significant colour change.

After 3 months, samples of all jars preservative fluids were collected and analysed with UV-Vis spectroscopy (Nanodrop™ One Thermo Fisher™, range 0-750nm) in order to identify the pigments responsible for their colouration.

Table 3. All specimens in 70% ethanol with no prior fixation (OE) on the day of preparation (T_0). © UR-Arc CR 2021.

At the beginning of the second phase of the project, in February 2021, new images and colorimetric measurements were taken, 14 to 18 months after preparation depending on the sets. Colorimetry measurements were also made on some of the test-tubes sampled for UV-Vis analyses to see if any change had occurred.

Finally, investigations were carried out on the specimens to evaluate the structural integrity of the plants. A manipulation test, consisting of light bending and applied pressure, assessed their stiffness and flexibility of the specimens.

Results and discussion

Colouration of the preservative fluid

Table 4 to Table 6 show the ΔE values for all experiment-jars at different milestones of the monitoring period: after 7 days, 3 months and approximately 1.5 years (14 months and 18 months depending on the set). The greater this value, the more the colour diverges from the clean fluid, correlating to a bigger proportion of pigments leaching into the fluid. A red gradient highlights values the set threshold of *ΔE=10*. This allows to point at general trends, both related to the type of specimen and the type of preparation fluid. These tables make it clear that specimens for set 2, known for their dying properties, released more pigments in all preparations. Overall, all specimens seem to release more colour in ethanol preservative (Table 4).

After 3 months (Table 5), all samples from set 2, except dry walnuts in ethanol (OE), have passed the *ΔE=10* threshold. Regarding set 1, preparations preserved in ethanol all performed poorly, apart from the ones fixed in FAA (AE).

The last measurements taken on both sets after approximately 1.5 years bring some interesting new information (Table 6). Two opposite trends appear:

- Δ*E* of some experiment-jars seem to have stabilized or slowly increased. This was observed on the following samples: all
- Lavender jars, Mint in OE, AE, OR_E, OR, OF, AF, OG, FG, AG, Chili in AE, OR, OF, AF, OG, FG, AG, Fresh Walnut in OR, AF, OG, FG, AG and Dry Walnut in OE, FE, OR_E OR, OF, AF, OG, AG.
- Δ*E* have significantly dropped for some
- other samples: Mint in FE, Chili in OE, FE, OR_E, All Beetroot jars, Fresh walnut in OE, FE, AE, OR_E, AF, and Fresh Walnut in AE, FG.

By plotting Δ*E* /Time for each experiment-jar (Figures 2-7), it is possible to show the rate at which a specimen released pigments in each preparation. Colour changes in the non-alcoholic preservatives increased slowly throughout the monitoring period, whereas the colour changes in the jar containing ethanol started abruptly before stabilizing over time. Moreover, experiment-jars using alcohol (either ethanol or rum) as preservative tend to show a Δ*E* slowly decreasing as the fluid returned to a colour closer to the fresh preservative's. This is best observed for the beetroot (Figure 3), where Δ*E* for 70% ethanol (OE), white rum (OR) and 70% ethanol with fixation in white rum (OR_E) jars quickly went to high values during the first 1-3 months before decreasing. Similarly, all chili pepper samples (Figure 6) preserved in alcohol not only reached significantly higher Δ*E* values but had returned to lower values at the end of the monitoring period. Looking at the photographic documentation of the jars, the behaviour of Δ*E* can directly be correlated with the colouration of the fluid.

Table 4. ΔE after the first week for each specimen in jar. Values above 10 are highlighted with a gradient.

ΔE T7	OE	FE	AE	OR_E	OR	OF	AF	OG	FG	AG	Max	Min
Lavender	8.23	7.44	3.76	3.06	2.82	2.46	2.07	2.66	1.18	1.65	8.23	1.18
Mint	9.84	15.67	4.66	4.23	3.91	1.67	1.33	2.00	1.22	1.85	15.67	1.22
Chili pepper	9.33	22.54	13.69	1.31	0.59	0.45	0.68	0.44	1.12	1.02	22.54	0.44
Beetroot	36.70	39.25	22.11	37.09	38.71	29.88	25.81	41.22	12.10	9.31	41.22	9.31
Fresh walnut	33.61	29.90	30.46	29.32	30.75	22.68	19.94	28.45	7.65	4.96	33.61	4.96
Dry walnut	1.78	7.20	7.16	9.88	10.04	19.01	30.33	4.40	3.21	1.26	30.33	1.26
Max	36.70	39.25	30.46	37.09	38.71	29.88	30.33	41.22	12.10	9.31		
Min	1.78	7.20	3.76	1.31	0.59	0.45	0.68	0.44	1.12	1.02		

Table 5: ΔE after 3 months for each specimen in jar. Values above 10 are highlighted with a gradient.

ΔE T91	OE	FE	AE	OR_E	OR	OF	AF	OG	FG	AG		Min
Lavender	9.76	6.32	4.40	2.89	4.26	6.78	4.40	6.04	4.51	0.99	9.76	0.99
Mint	11.12	13.78	3.82	10.00	5.00	9.81	3.82	3.44	3.64	0.70	13.78	0.7
Chili pepper	21.30	27.40	1.64	16.36	2.66	2.60	1.64	1.96	1.60	1.90	27.4	1.6
Beetroot	44.63	35.34	25.52	25.35	35.01	32.46	25.52	37.58	34.50	21.47	44.63	21.47
Fresh walnut	35.01	35.16	31.44	32.52	33.08	30.84	31.44	34.40	21.15	26.23	35.16	21.15
Dry walnut	7.27	17.34	33.47	15.95	30.12	31.90	33.47	15.10	35.27	16.34	35.27	7.27
Max	44.63	35.34	33.47	32.52	35.01	32.46	33.47	37.58	35.27	26.23		
Min	7.27	6.32	1.64	2.89	2.66	2.60	1.64	1.96	1.60	0.70		

Table 6. ΔE after 14 months (set 2: Beetroot, Fresh and Dry Walnut) or 18 months (set 1: Lavender. Mint. Chili pepper). Values above 10 are highlighted with a gradient.

ΔE T455/596	OE	FE	AE	OR_E	OR	OF	AF	OG	FG	AG	**Max**	*Min*
Lavender	8.47	6.76	8.42	4.19	6.83	9.82	4.73	9.31	8.09	4.46	9.82	4.19
Mint	12.49	12.58	8.98	10.65	5.91	15.60	4.82	5.27	8.31	3.69	15.60	3.69
Chili pepper	14.64	22.87	19.66	10.35	4.62	5.12	3.44	3.12	2.97	2.23	22.87	2.23
Beetroot	17.60	29.25	16.65	6.23	22.53	29.85	22.92	34.80	31.98	21.14	34.80	6.23
Fresh walnut	34.84	34.40	32.80	31.69	33.52	31.75	30.66	36.76	29.26	32.67	36.76	29.26
Dry walnut	19.02	28.01	30.15	28.73	31.86	34.23	34.18	32.39	33.16	18.27	34.23	18.27
Max	34.84	34.40	32.80	31.69	33.52	34.23	34.18	36.76	33.16	32.67		
Min	8.47	6.76	8.42	4.19	4.62	5.12	3.44	3.12	2.97	2.23		

After 3 months (T91-92), fluid samples from each experiment-jar was sampled to be analysed by UV-vis spectroscopy, in order to detect characteristic peaks of some of the natural pigments thought to have leached from the specimen. According to reference spectra, polyphenolic tannins have peak in UV absorption between 200-300 nm (Grasel & al. 2016), chlorophylls peak twice: around 450nm and 650nm (Taniguchi & Lindsey 2021), betalains peaks at ~480nm and 550nm (Sengupta & al. 2015) carotenoids peak multiple times in a broad range of 400-500nm (Domenici et al. 2014). It was possible to identify the profile of polyphenolic tannins UV-absorption in both the dried and fresh walnuts fluids (Figure 8, Figure 9), as well as in lavender, mint (Figure 10, Figure 11) and maybe Chili pepper (Figure 13). Betalains were clearly identified in beetroot fluids (Figure 12). Chlorophyll peaks were visible in the mint fluids (Figure 11) and some of the Chili pepper peaks can be attributed to carotenoid compounds (Figure 13).

In addition to giving indications of the compounds extracted from the specimen, a clear correlation can be made between high ΔE value (Figures 2-7) and high absorption in the UV-vis spectra (Figures 8-13). For instance, walnuts and Beetroots jars, with a dark fluid at the time of sampling, showed absorptions reaching values up to 20-30 (Figures 8, 9 and 12), whereas the lighter fluids from mint and lavender jars barely exceed an absorption of 5 (Figure 10-11).

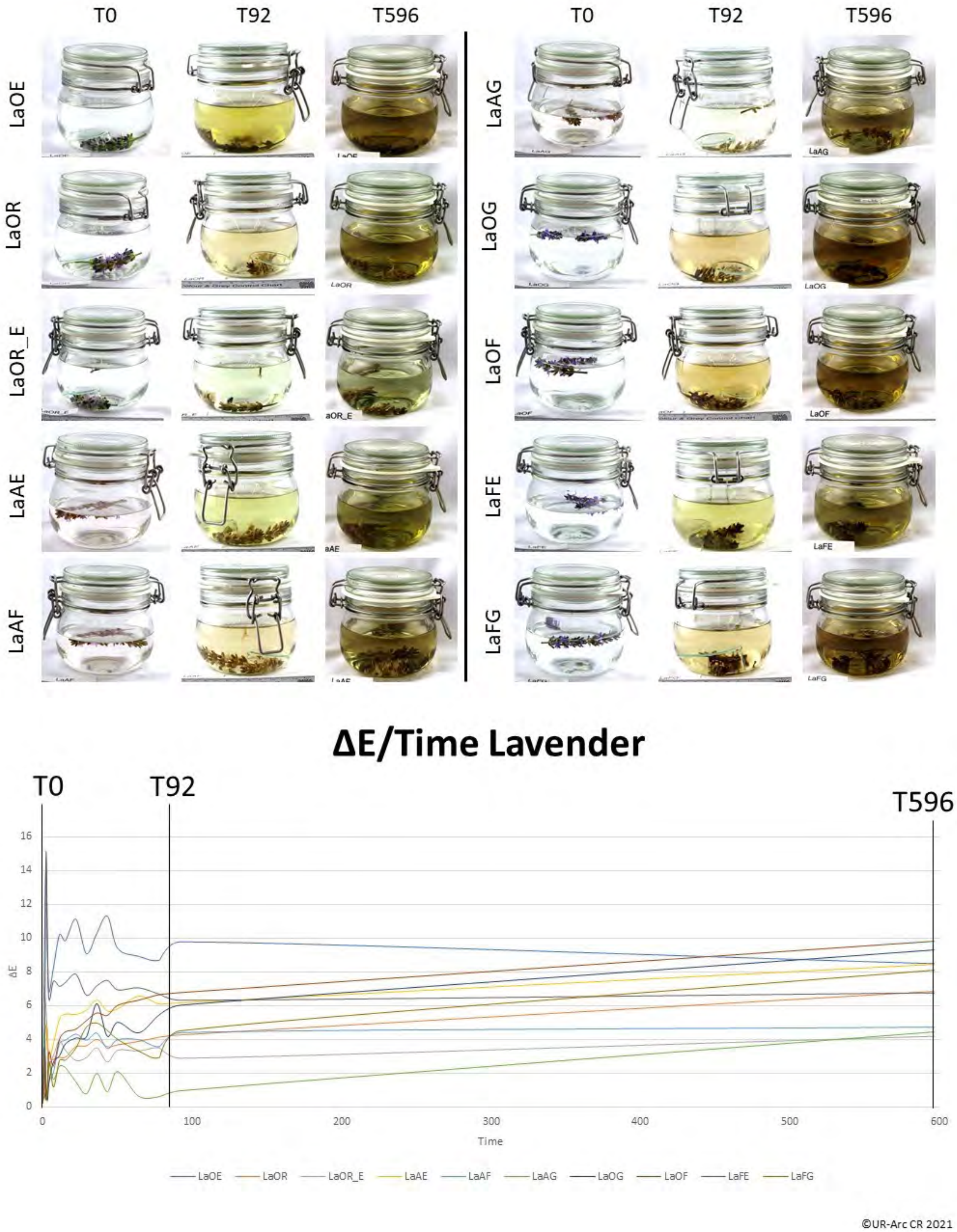


Figure 2: ΔE/time and photos at time of preparation, 3 months and 18 months for Lavender. © UR-Arc CR 2021.

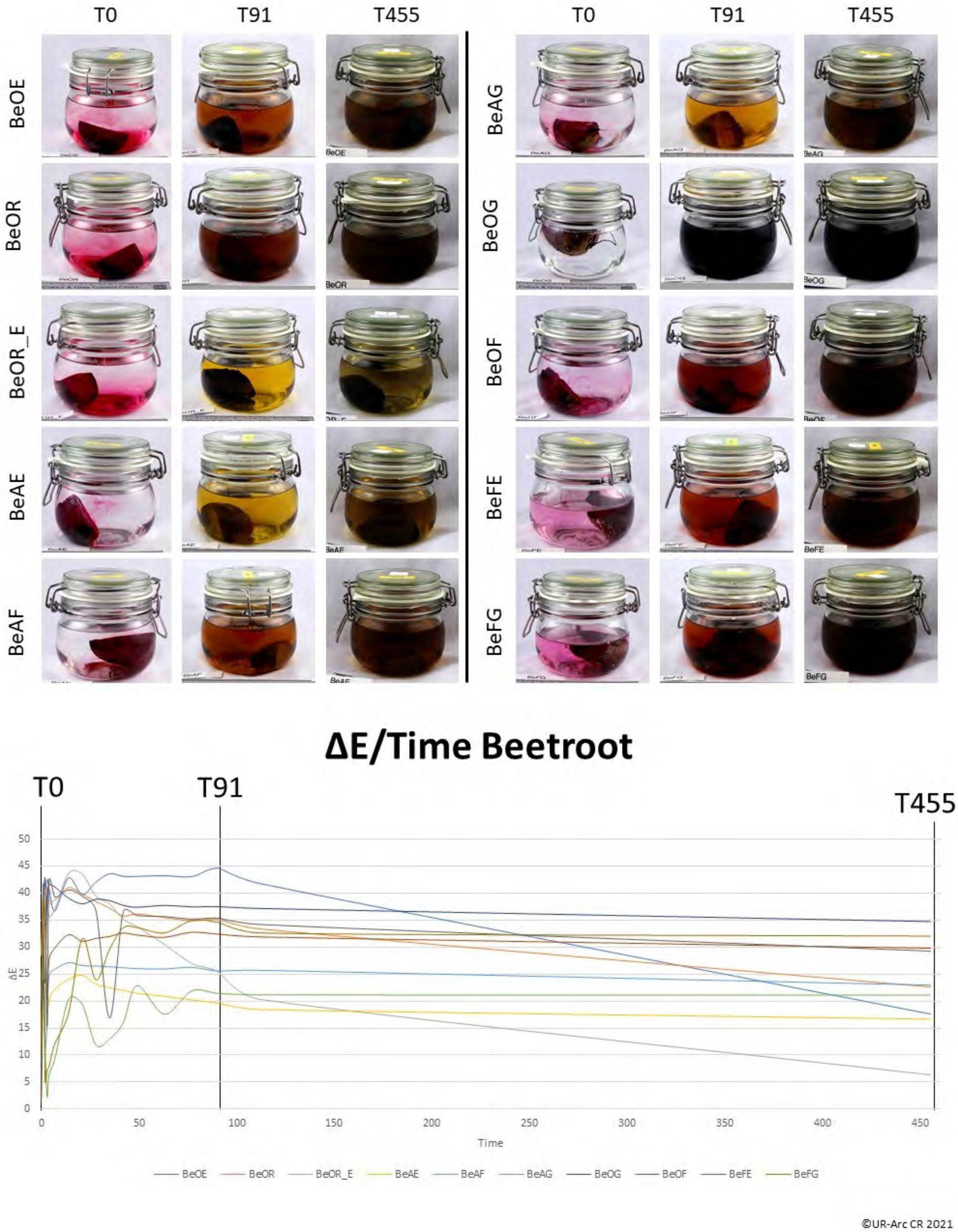


Figure 3: ΔE/time and photos at time of preparation, 3 months and 14 months for Beetroot. © UR-Arc CR 2021.

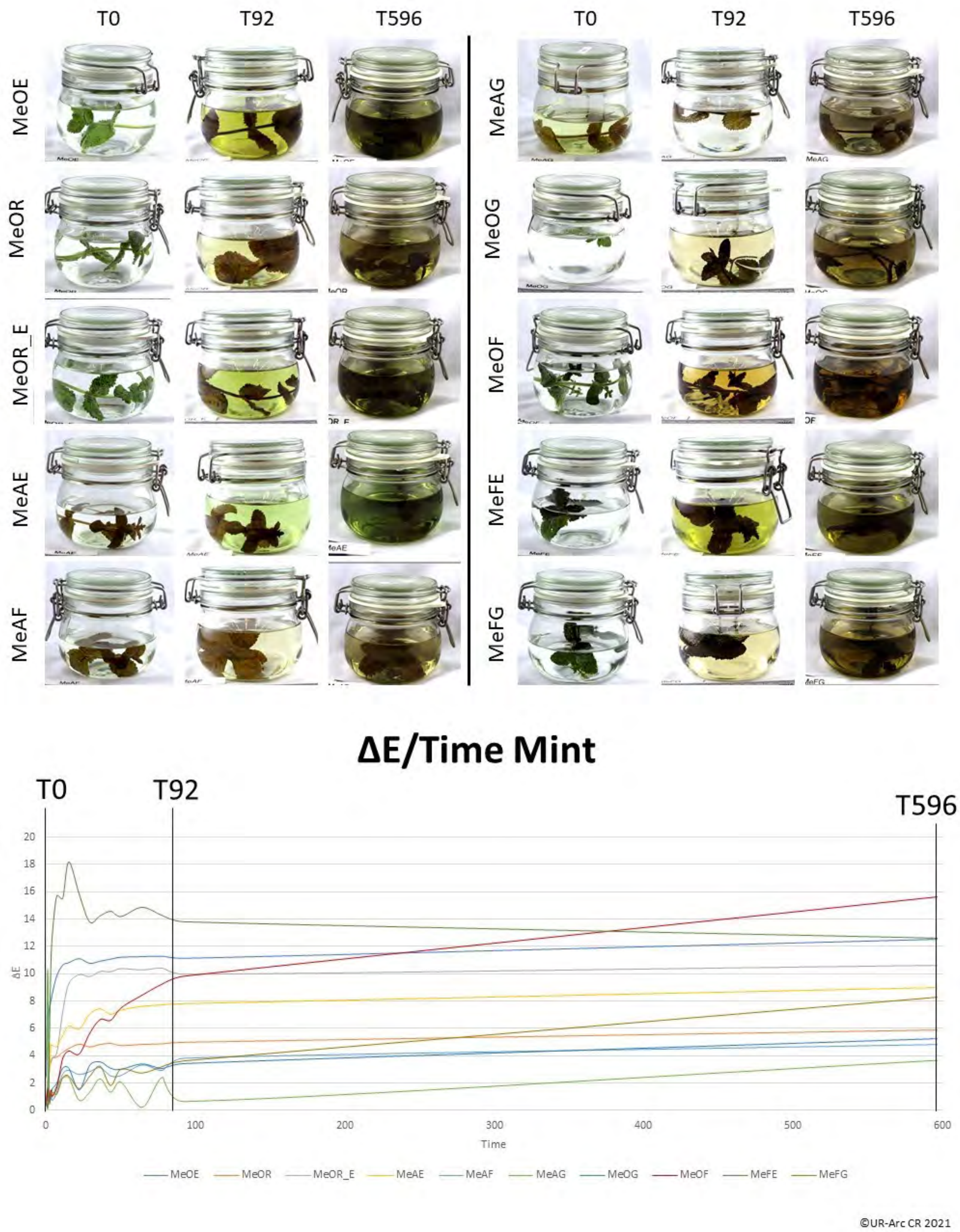


Figure 4. ΔE/time and photos at time of preparation, 3 months and 18 months for Mint. ©UR-arc CR 2021.

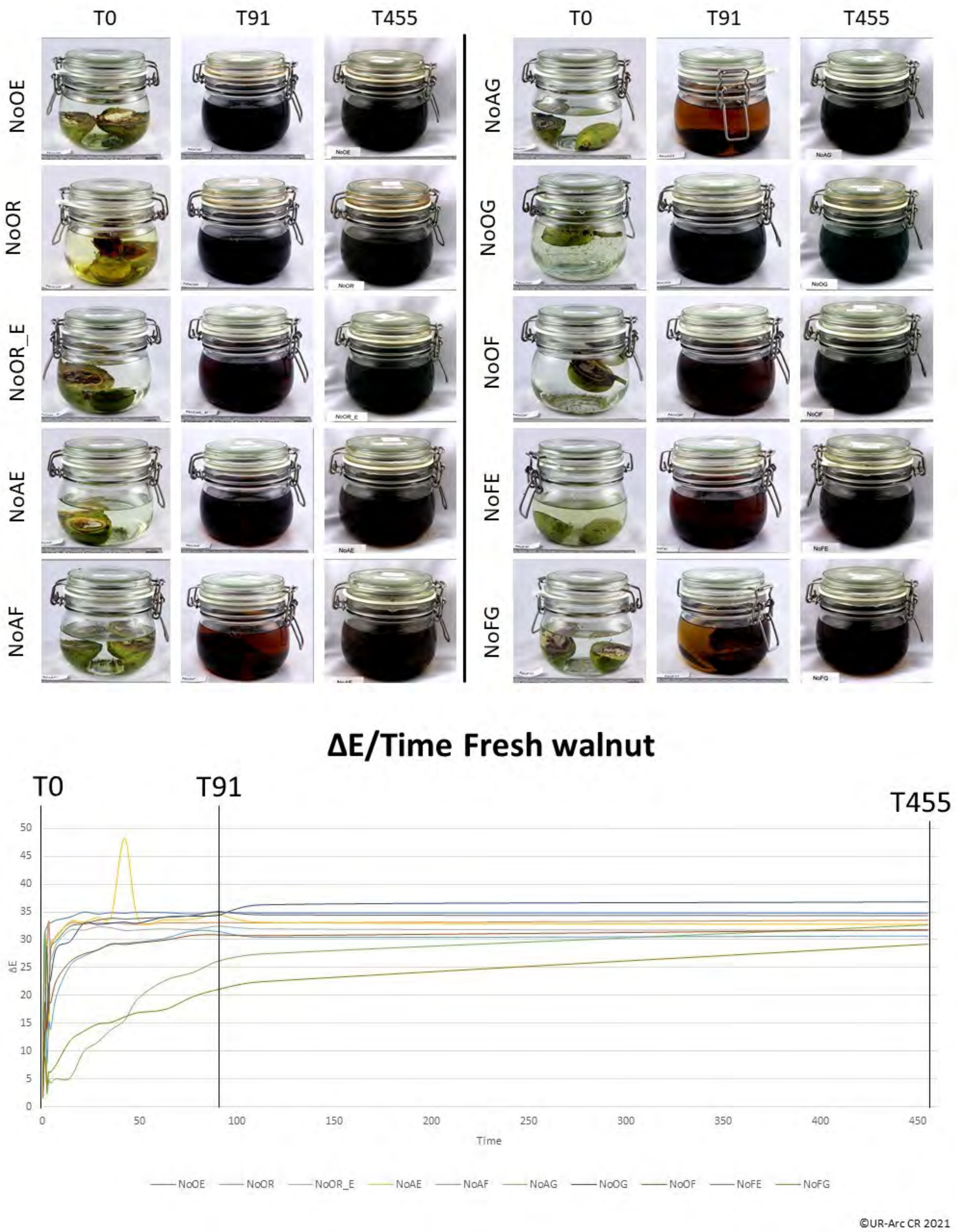


Figure 5. ΔE/time and photos at time of preparation, 3 months and 18 months for Fresh Walnut. © UR-Arc CR 2021.

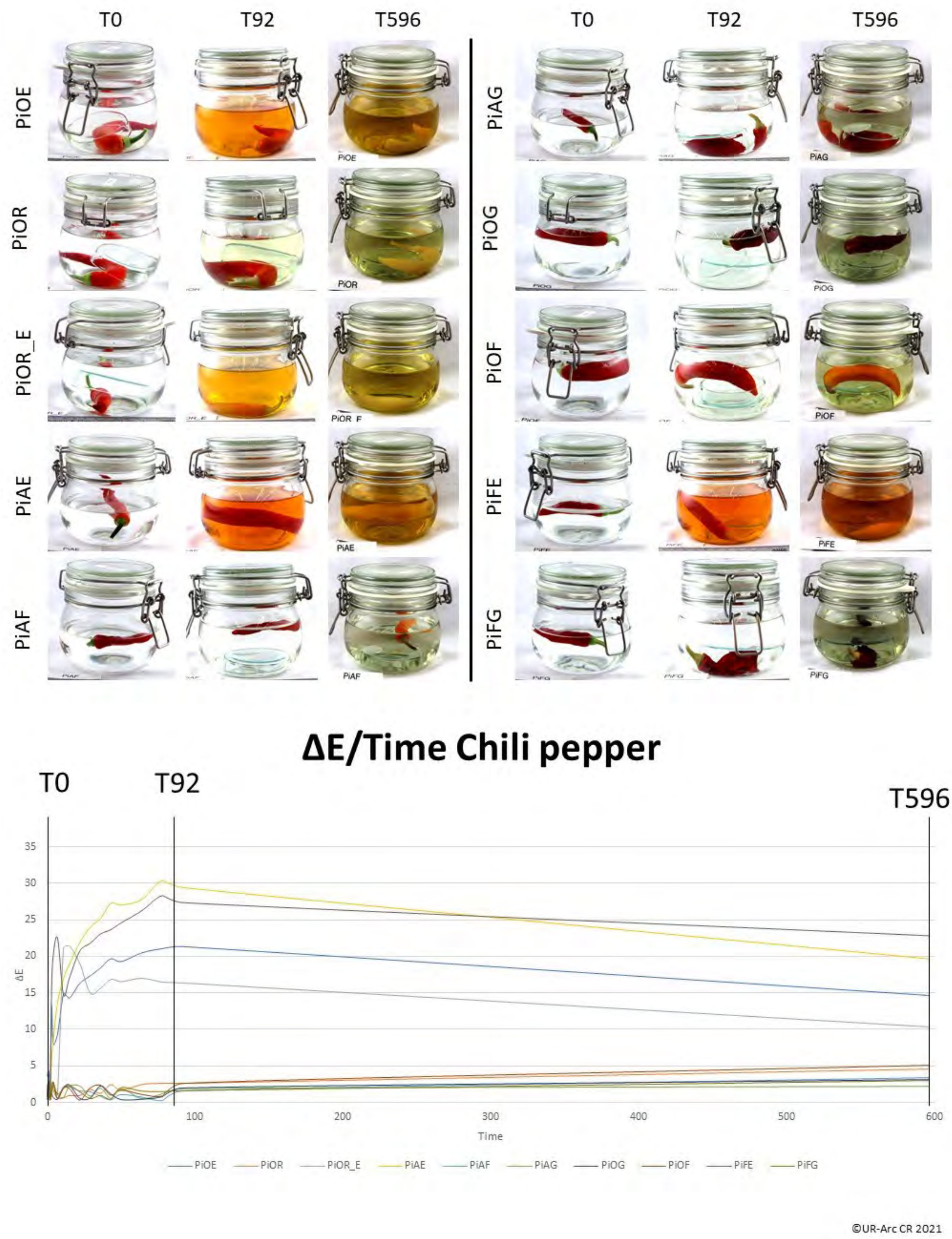


Figure 6. ΔE/time and photos at time of preparation, 3 months and 18 months for Chili Pepper. © UR-Arc CR 2021.

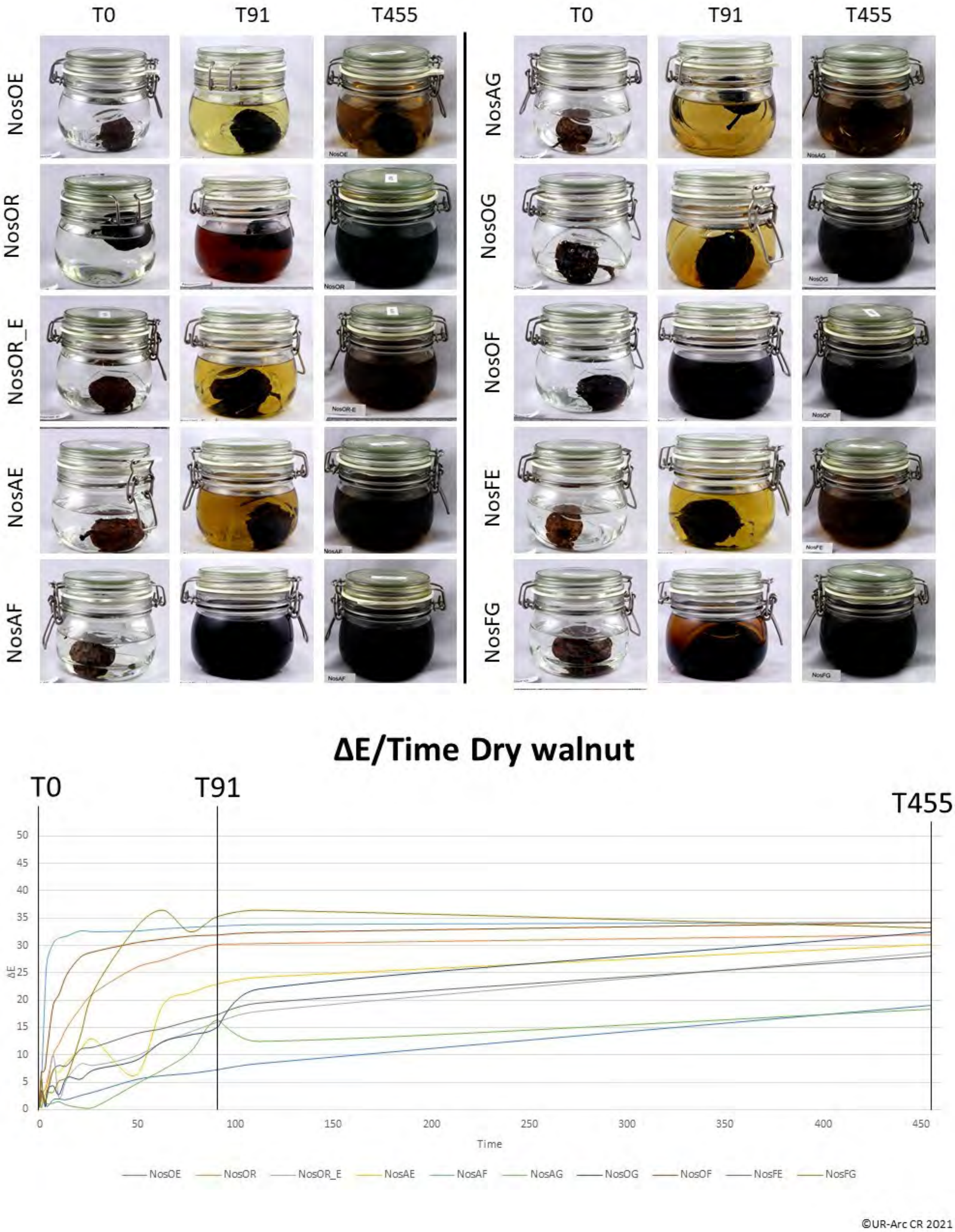


Figure 7. ΔE/time and photos at time of preparation, 3 months and 18 months for Dry Walnut. © UR-Arc CR 2021.

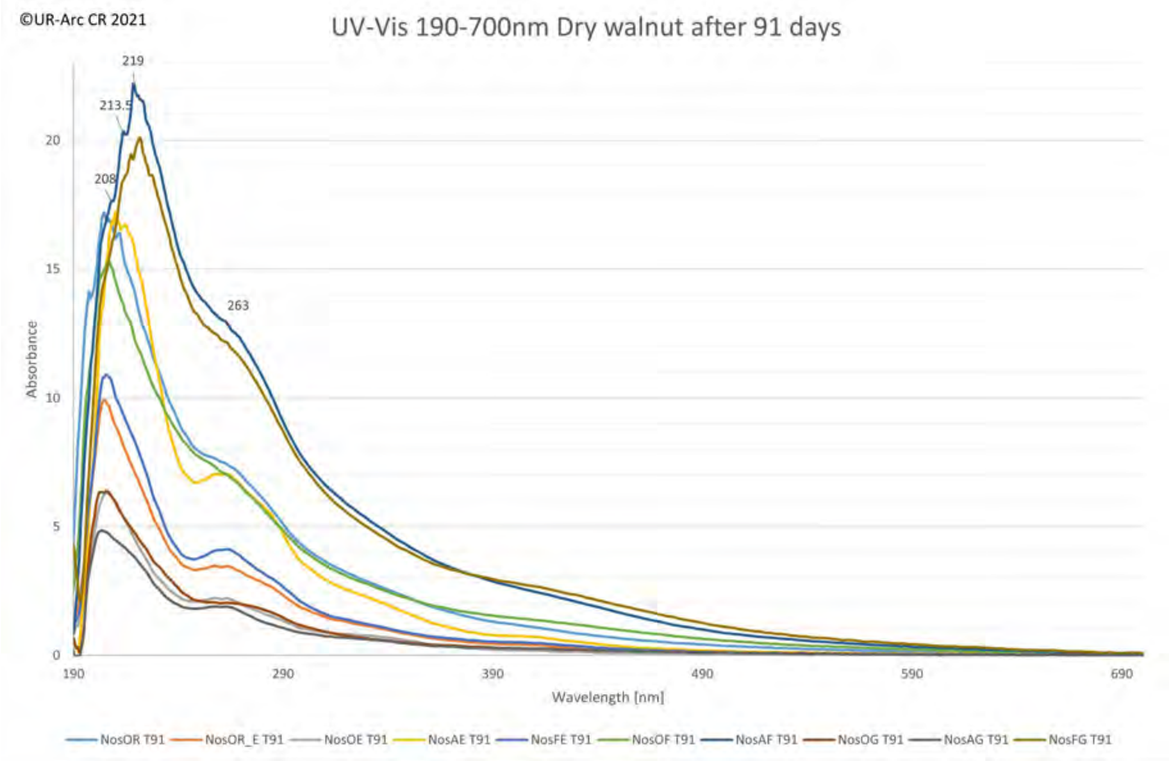


Figure 8. UV-Vis absorption spectra on Dry walnut fluids. © UR-Arc CR 2021.

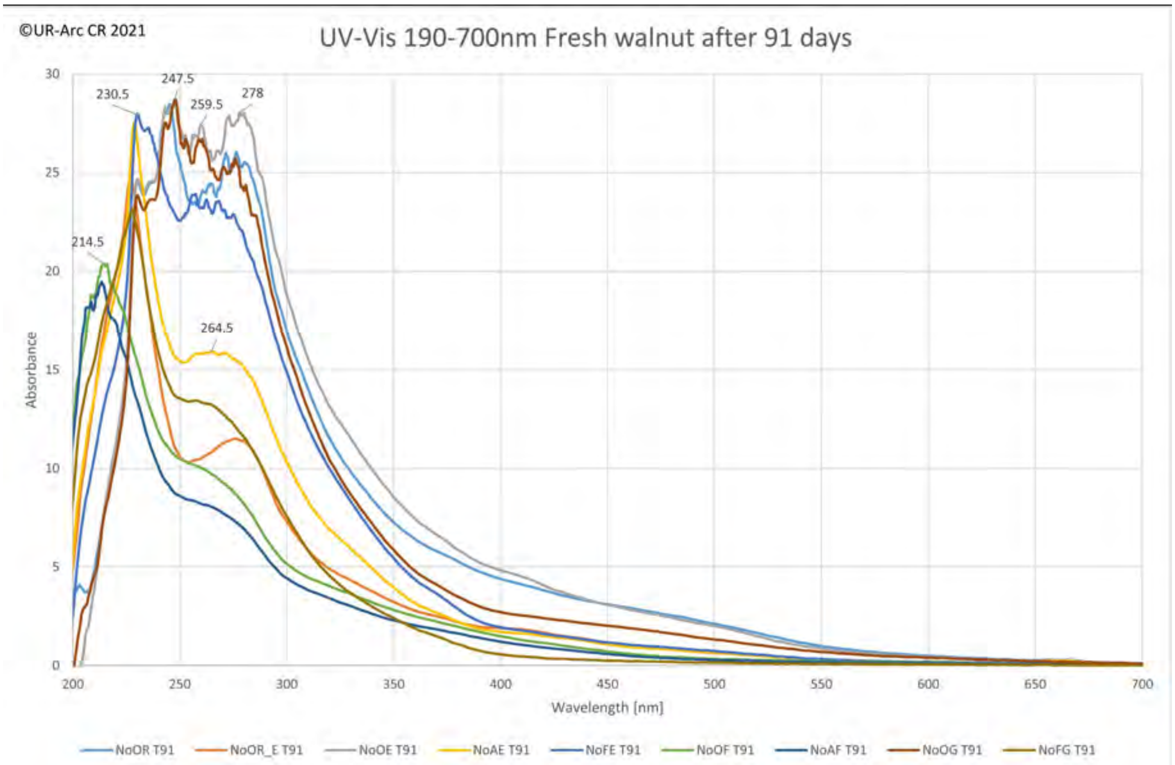


Figure 9. UV-Vis absorption spectra on Fresh walnut fluids. © UR-Arc CR 2021.

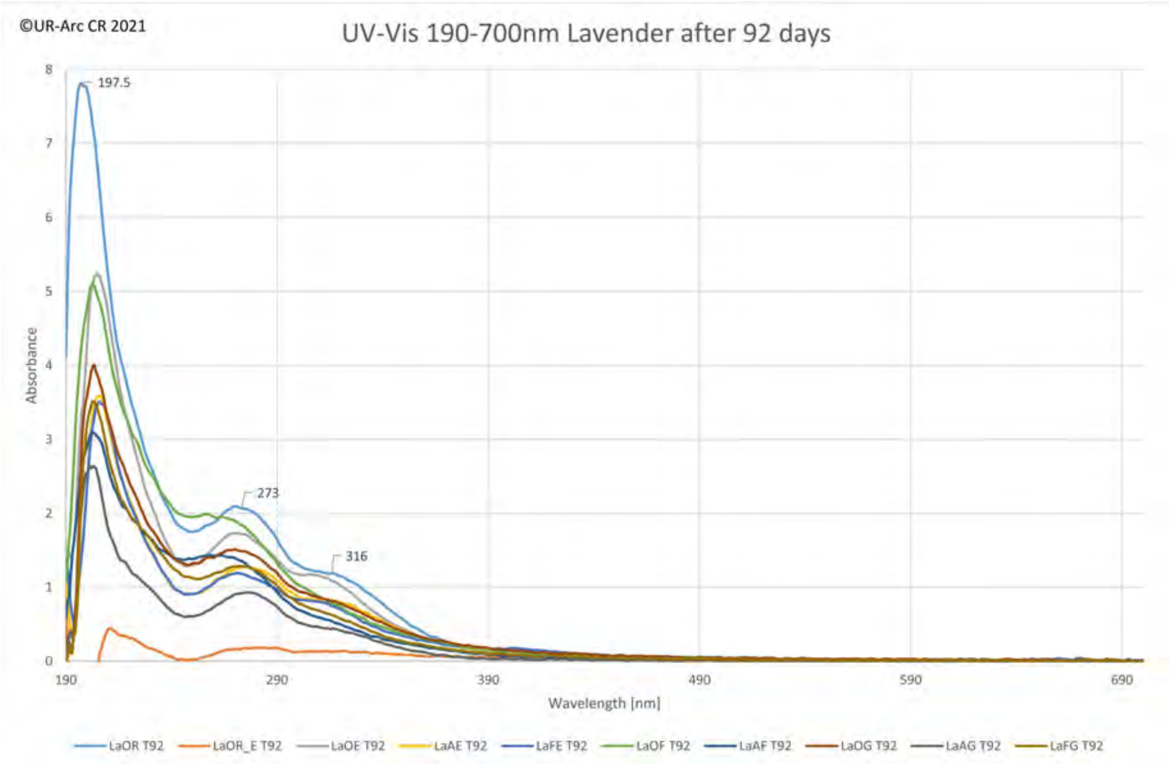


Figure 10. UV-Vis absorption spectra on Lavender fluids. © UR-Arc CR 2021.

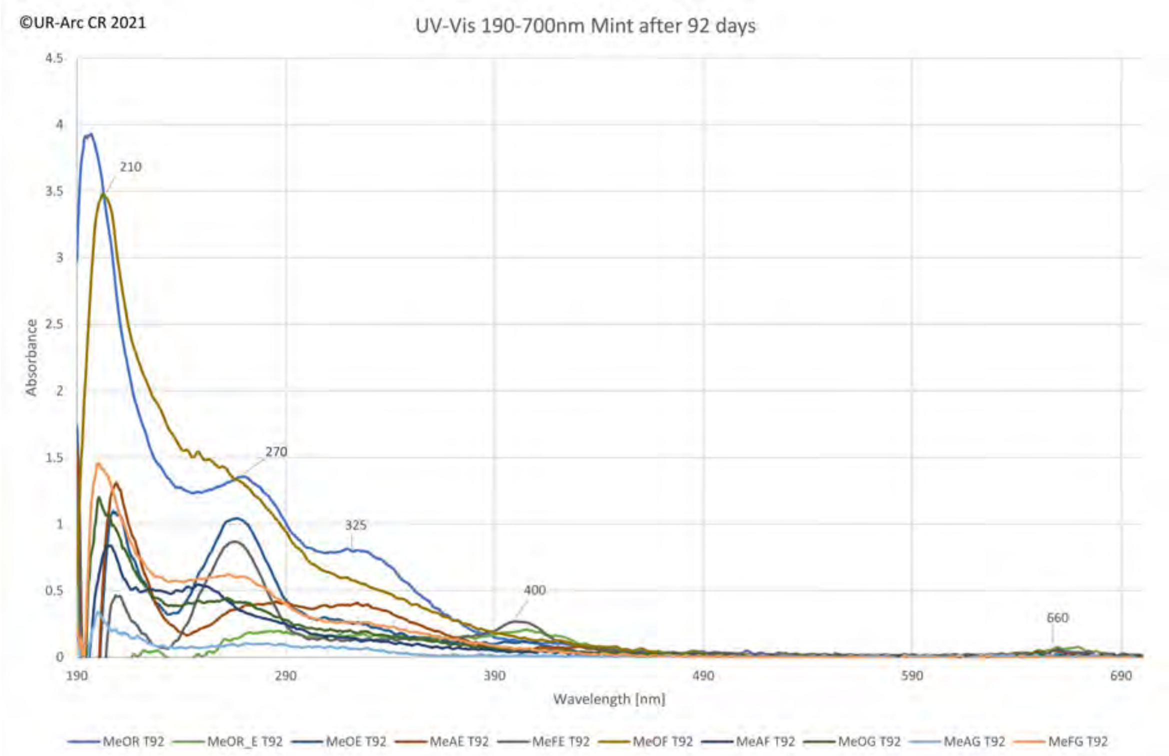


Figure 11. UV-Vis absorption spectra on Mint fluids. © UR-Arc CR 2021.

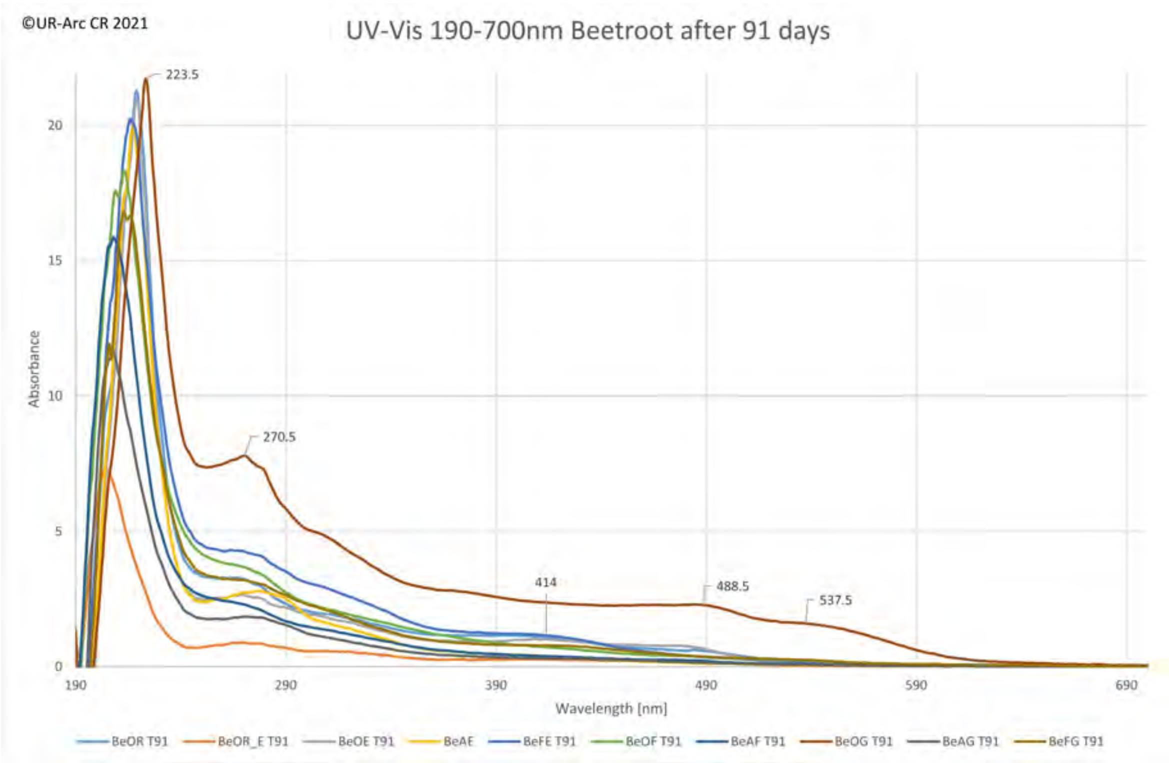


Figure 12. UV-Vis absorption spectra on Beetroot fluids. © UR-Arc CR 2021.

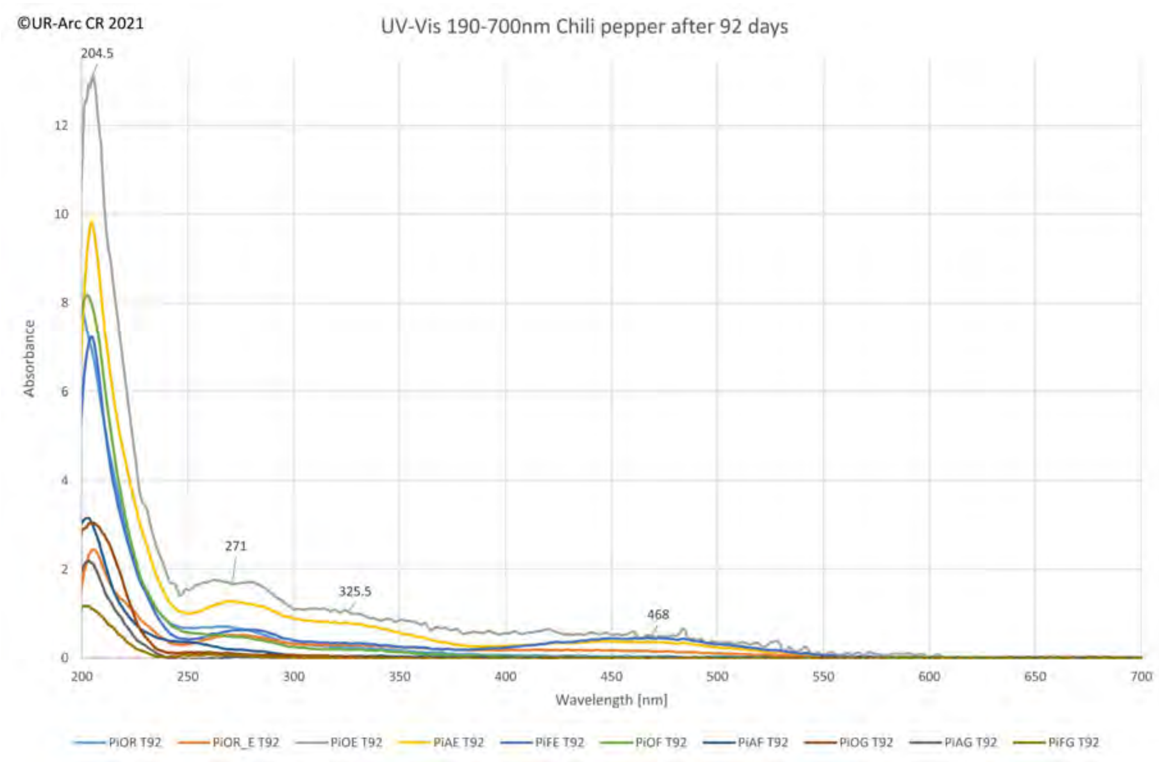


Figure 13. UV-Vis absorption spectra on Chili pepper fluids. © UR-Arc CR 2021.

Degradation of the leached pigments in the fluids

Photographs taken on the same day of colorimetry measurements allow us to link an increasing ΔE to the leaching of colour from the specimen into the fluid, and a decreasing ΔE to the overall discolouration of the tainted fluid (Figures 2-7). The hypothesis was that the pigments were degrading once inside the fluid, and that this process was mostly happening with alcohol-based solutions. To test this, the samples that were collected from the jars for the UV-Vis analysis were kept in test tubes conserved in the dark and re-measured with the spectrophotometer after 14-18 months. The specimen could not contribute to the concentration of pigments in the fluid anymore, allowing observations to be made in regard to the interactions between pigments and fluid.

The CIELAB values obtained on those test-tubes were very different from the ones obtained on the day the fluid was sampled. This shows that the colour of the fluid changed even in the absence of the specimen. Tables 9, 10 and 11 report the overall change (Δ*E*), but also in which direction the variation occurred: change in saturation (Δ*L**) or change in hue (Δ*a** and Δ*b**) between the time of sampling (T91-92) and the second measurement (1.5 year). Δ*E* is a strictly positive value. Δ*L**, Δ*a** and Δ*b** are differential equations ($\Delta X = x - x_0$) (X-Rite Pantone, 2016), where:

Δ*L**
[+] : brighter / less dark
[-] : darker / less bright

Δ*a**
[+] : redder / less green
[-] : greener / less red

Δ*b**
[+] : yellower / less blue
[-] : bluer / less yellow

Overall, alcohol-based preservatives showed the biggest colour change. Samples from the Mint (Me) experiment-jars (Table 9) show very little changes, with a $\Delta E<5$. These changes mainly occurred on the *L** and *b** values. These values translate to a change from brighter green or yellow (Figure 4, T92) to a nearly transparent fluid. To the observer, this scale of change is hardly noticeable. It must be noticed that this trend has not been observed on the experiment-jars themselves, who kept darkening after 18 months due to the presence of the specimen, continuing to release pigments.

Beetroot fluids showed the highest Δ*E*, ranging from 5 to 22, with the changes mainly occurring in the *a** and *b** values (Table 10). The jars had a wide range of saturation (*L** from 26 to 59) of warm yellow-brown colour at the time of sampling (Figure 3, T91).

By the time of the second measurement, all fluids of unfixed specimens in alcohol-based preservatives, OE, OR, OR_E, had noticeably changed ($\Delta E>10$). For the Chili peppers fluids, only specimens in alcohol-based fluids had a distinct colouration at the time of sampling (Figure 6, T92). They were also the ones undergoing bigger colour changes (Higher Δ*E*) (Table 11).

Integrity of the specimen

The photographic documentation as well as frequent observations of the jars allowed assessments to be made in relation to the conservation state of the specimens during the monitoring period. Multiple alterations have been noticed and classified in 6 groups (Table 12).

Discussion

The results presented above tend to corroborate the empirical observations made in the Botanical Museum of Zurich University and other collections and clearly show that depending on the specimen, discolouration problems occur in different fluids and at different rates. The classification of specimens in two sets based on their colour preservation problem ended up being relevant. Indeed, when the solubility of the pigment and its location in the cell is considered, the different trends observed during the tests start to make sense. The pigments mainly responsible for the colour of specimens from set 1 are chlorophylls and carotenoids, stored in the chloroplasts (Buchanan, Gruissem, and Jones, 2015). These specimens tend to leach their pigments quickly in alcohol-based preservative such as ethanol independently of the fixation process. Indeed, ethanol is known to be a great extracting agent, since it increases membrane permeability (Goldstein, 1986; Hendry, Houghton, and Brown, 1987). Those same pigments are also known to be very sensitive, explaining why they degraded inside the fluid after a certain time. However, either due to the light colour of the pigments or their lower concentration in the jar, this leaching was not enough to opacify the fluid to the point of masking the specimen from view. In comparison, specimens with strong dying properties from set 2 owe their colour to water soluble pigments stored in the vacuole (Buchanan, Gruissem, and Jones, 2015; Delgado-Vargas, Jiménez, and Paredes-López, 2000). They were all darker and more voluminous than the specimens from set 1, and leached so

Table 9. Delta E, L a* and b* for Mint (Me) sampled fluids*

	Mint			
	sample	**L**	**a**	**b**
JARS T92	MeOE	60.93	-3.81	11.52
	MeOR	59.80	-1.85	5.59
	MeOR_E	60.61	-4.29	10.08
	MeAE	60.30	-4.12	7.56
	MeAF	59.48	-0.83	3.48
	MeAG	62.44	-0.60	1.86
	MeOG	61.52	-0.94	4.73
	MeOF	58.12	-1.27	9.73
	MeFE	59.14	-4.62	13.73
	MeFG	62.43	-1.11	5.22
TUBES T92	MeOE	58.39	-3.14	8.52
	MeOR	58.14	-1.88	6.45
	MeOR_E	56.93	-4.07	8.73
	MeAE	58.39	-4.22	7.22
	MeAF	59.22	-0.75	3.03
	MeAG	60.74	-0.57	2.14
	MeOG	59.63	-0.74	4.20
	MeOF	57.90	-1.31	8.74
	MeFE	57.98	-3.98	10.11
	MeFG	59.80	-0.96	4.71
Tube - jar	**ΔE**	**ΔL**	**Δa**	**Δb**
MeOE	3.99	-2.54	0.67	-3.00
MeOR	1.87	-1.66	-0.03	0.86
MeOR_E	3.93	-3.68	0.22	-1.35
MeAE	1.94	-1.91	-0.10	-0.34
MeAF	0.53	-0.26	0.08	-0.45
MeAG	1.72	-1.70	0.03	0.28
MeOG	1.97	-1.89	0.20	-0.53
MeOF	1.01	-0.22	-0.04	-0.99
MeFE	3.85	-1.16	0.64	-3.62
MeFG	2.68	-2.63	0.15	-0.51

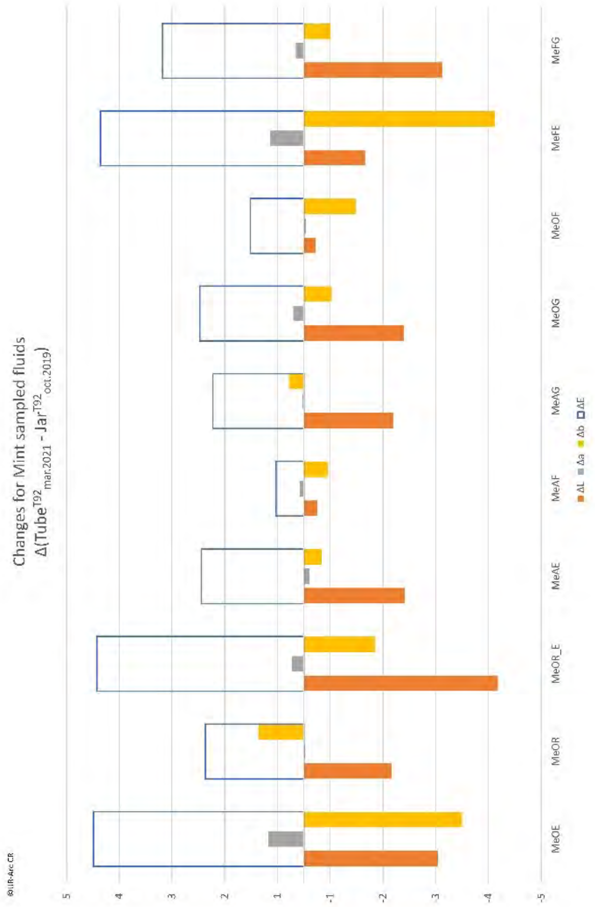
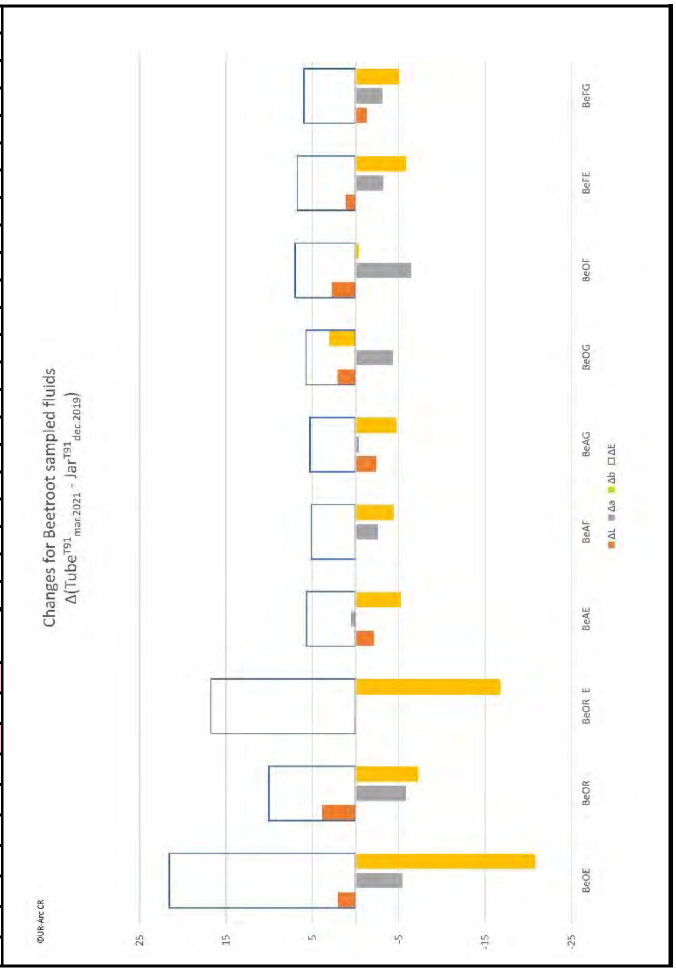


Table 10. Delta E, L a* and b* for Beetroot (Be) sampled fluids.*

	Beetroot			
	sample	**L**	**a**	**b**
JARS T91	BeOE	52.44	6.40	43.95
	BeOR	46.83	8.08	31.87
	BeOR_E	58.84	-0.75	26.10
	BeAE	59.30	-1.92	20.27
	BeAF	54.16	3.87	24.66
	BeAG	58.04	0.33	22.57
	BeOG	26.97	9.93	3.14
	BeOF	46.08	13.59	25.20
	BeFE	50.43	6.87	33.39
	BeFG	47.92	11.73	30.25
TUBES T91	BeOE	54.47	0.96	23.18
	BeOR	50.66	2.25	24.63
	BeOR_E	58.93	-0.87	9.34
	BeAE	57.17	-1.42	15.05
	BeAF	54.21	1.28	20.22
	BeAG	55.68	-0.06	17.85
	BeOG	29.07	5.58	6.23
	BeOF	48.82	7.14	24.8
	BeFE	51.55	3.64	27.57
	BeFG	46.67	8.63	25.26
Tube - jar	**ΔE**	**ΔL**	**Δa**	**Δb**
BeOE	21.57	2.03	-5.44	-20.77
BeOR	10.05	3.83	-5.83	-7.24
BeOR_E	16.76	0.09	-0.12	-16.76
BeAE	5.66	-2.13	0.50	-5.22
BeAF	5.14	0.05	-2.59	-4.44
BeAG	5.29	-2.36	-0.39	-4.72
BeOG	5.73	2.10	-4.35	3.09
BeOF	7.02	2.74	-6.45	-0.40
BeFE	6.75	1.12	-3.23	-5.82
BeFG	6.01	-1.25	-3.10	-4.99



much that the fluid in most jars was completely dark at the end of the monitoring period. These specimens released pigments at a steadier rate when preserved in alcohol. However, they tend to release more pigments when put in contact with formaldehyde, either as fixative or preservative fluid, probably because these pigments are water soluble.

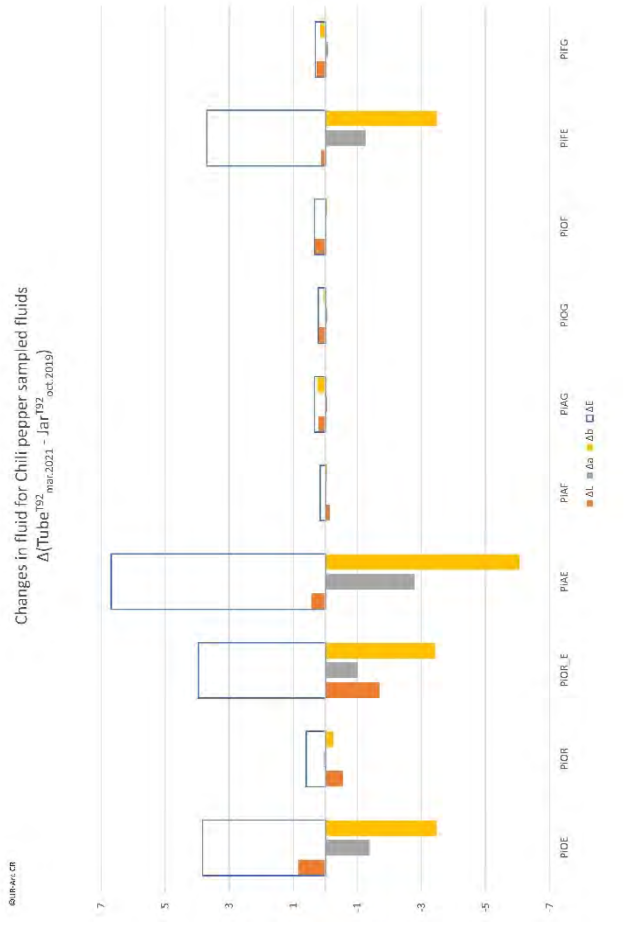
The interpretation of the UV-Vis spectra was carried out by comparison with data found in the literature and a good indication of the type of pigments could be obtained. Moreover, it was possible to correlate the intensity of the absorption spectra with the importance of the colour change (ΔE), as well as confirm the degradation process of the leached pigments in alcohol-based preservatives.

Specimens from both sets showed, overall, less discolouration when fixed and then preserved in 70% glycerol. However, colour is not the only feature to be preserved, and glycerol at such high concentration caused severe shrinkage in fleshy specimens. Moreover, glycerol-preserved specimens require stricter climate control for their storage, in order to prevent moulding issues (Van Dam, 2018). Other changes such as softening and stiffening of the tissues have also been observed. Based on the simple manipulation-test on these two sets, they seem to be fluid-dependent. For instance, alcohol-based preservatives seem to stiffen all specimens, whereas glycerol seems to cause shrinkage in fleshy specimens (i.e. fruits) and FAA caused softening in thinner tissues. Further investigations are needed, and microscopic observations on the specimens, as well as pH measurements have already been added to the monitoring protocol for the new ongoing sets of tests. Other historical or modern preservatives will also be incorporated in the future experiments.

It now seems evident that grouping the colour alterations under the same "discolouration" label only makes sense with regards to how it affects the preservative fluid, but it gives very little

Table 11. Delta E, L a* and b* for Chili pepper (Pi) sampled fluids.*

	Chili pepper			
	sample	L	a	b
JARS T92	PiOE	55.88	3.97	20.75
	PiOR	60.72	-1.15	3.39
	PiOR_E	59.86	1.27	17.07
	PiAE	55.03	7.18	28.40
	PiAF	60.65	-0.67	1.22
	PiAG	61.21	-0.57	1.42
	PiOG	61.13	-0.58	1.61
	PiOF	59.85	-0.83	1.84
	PiFE	54.79	7.56	26.04
	PiFG	61.51	-0.53	1.48
TUBES T92	PiOE	56.72	2.59	17.28
	PiOR	60.18	-1.11	3.15
	PiOR_E	58.16	0.25	13.64
	PiAE	55.45	4.40	22.34
	PiAF	60.51	-0.69	1.16
	PiAG	61.43	-0.62	1.67
	PiOG	61.33	-0.65	1.67
	PiOF	60.18	-0.86	1.78
	PiFE	54.91	6.31	22.56
	PiFG	61.77	-0.61	1.63
Tube - jar	**ΔE**	**ΔL**	**Δa**	**Δb**
PiOE	3.83	0.84	-1.38	-3.47
PiOR	0.59	-0.54	0.04	-0.24
PiOR_E	3.96	-1.70	-1.02	-3.43
PiAE	6.68	0.42	-2.78	-6.06
PiAF	0.15	-0.14	-0.02	-0.06
PiAG	0.34	0.22	-0.05	0.25
PiOG	0.22	0.20	-0.07	0.06
PiOF	0.34	0.33	-0.03	-0.06
PiFE	3.70	0.12	-1.25	-3.48
PiFG	0.31	0.26	-0.08	0.15



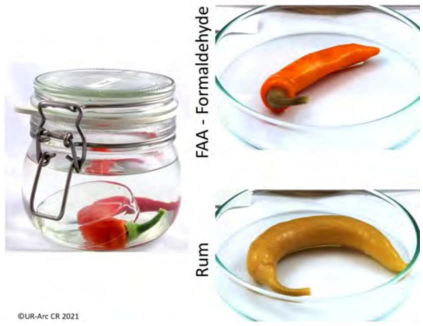
information about what is happening in the specimen. It would be more appropriate to refer to the colour alterations of the specimen in a conservation-assessment report as “lightening” or “darkening”. Indeed, in a specimen, some pigments are released in the fluid when others stay in the plant. Therefore, in some cases (set 1), the specimen assumes a lighter colour. The remaining pigments can sometimes undergo molecular modifications, thus changing the specimen’s colour once again. This can manifest in the darkening, or yellowing, of leaves or browning of flowers for example. Darkening of the specimen also occurs if the leaching pigment has strong dying properties. This will not only opacify the fluid, but it can also affect other tissues from the specimen, making it look darker. This is what happens to the fresh walnuts, which darkened to a brown tone.

From those results, it appears that monitoring the colour change of a fluid to understand the discolouration problems of a specimen is not sufficient on its own. Only by cross-referencing colorimetric information with photographic documentation and closer observation of the specimen, was it possible to get a clearer picture of what was happening. However, such extended monitoring protocol can be difficult to achieve on the scale of a whole collection, and museums should choose simpler documentation protocols that are easier to maintain.

Conclusion

This paper presented the first results of an ongoing project carried out at the UR-arc CR of Neuchâtel, Switzerland. The aim was to gather experimental data on the discolouration problems identified in museum collections of botanical specimens. Two sets of experiment-jars containing

Table 12:.Alterations observed on the specimens.

<u>Discolouration / colour leakage:</u> Release of pigments from the specimen to the fluid. It gives the fluid a noticeable tint. In the most advance stage, this leads to the complete opacification of the fluid, masking the specimen.	
<u>Lightening:</u> Loss of colour. The specimen assumes a lighter colour. This often happened in alcohol-based preservatives but was also noted in other preservatives. The pigments thought to be sensitive to this alteration in the tested fluids are chlorophylls, carotenoids and anthocyanin flavonoids (Set 1).	
<u>Darkening:</u> The specimen assumes a duller colour, usually in the brown tones. The pigments more sensitive to this alteration in the tested fluids are mostly tannins.	
<u>Softening:</u> The specimen becomes soft. When removed from the fluid, it doesn't hold its shape. When manipulated out of the fluid, it is very flexible. In the most advanced stage, the tissues have a jelly texture and can look translucent. (Leaves fixed in FAA fixative)	
<u>Stiffening:</u> The specimen becomes stiff. When removed from the fluid, it holds its shape perfectly. When manipulated out of the fluid, it is very rigid with the potential for break-age. (Leaves in 70% ethanol and formaldehyde)	
<u>Shrinkage:</u> Could be due to dehydration, especially noticeable on fleshy specimens, such as fruits. Moreover, stiffening was often observed on the shrunk specimen. The tissues retracted, causing the specimen to look wrinkled or dry. (fruits and roots in glycerol and sometimes in ethanol)	

specimens were prepared following different fluid preservation protocols. The discolouration of the specimens was indirectly monitored by measuring the colouration of the fluid regularly for 3 months and once again after approximately 1.5 years.

Information on the change of colour in the fluid was obtained by spectrocolorimetry measurements in the CIELAB colour space, and expressed by computing (ΔE), the overall perceived difference between the clear fluid and the altered one. Finally, the leached pigments were partially identified by UV-vis spectroscopy. As expected, alcohol-based preservatives promoted the leaching of pigments from the specimens. The two tested fixatives, formaldehyde and FAA, gave different results depending on the specimen and the preservative fluid used. Finally, high concentration glycerol proved to be a good way to preserve colour but, in some cases, caused severe damage to the structural integrity of the tissues.

In conclusion, every specimen has a complex mix of pigments, varying in nature and concentration, even between individuals from the same species. All the pigments were found to have sensitivity to solvents and undergo different chemical degradation processes. Therefore, it is for now not possible to propose a "one fits all" recipe to preserve them. As it is often the case in conservation, one should have a case-by-case approach to the matter. The research continues and allows us to refine our test protocols.

Acknowledgements

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Serendipitous discovery of mites in the eye cavity of *Asota caricae* Fabricius, 1775 (Lepidoptera: Erebidae)

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Abstract

Natural history collections face threats of deterioration from various quarters especially arthropod pests. Identifying the breeding and hiding sites of such pests is imperative in maintaining museum collections. We report a serendipitous discovery of mites belonging to genus *Suidasia* from the eye of a recently dry-preserved moth during investigations with SEM. The discovery of a known pest of museum specimens hidden inside the insect highlights the extra care needed to preserve valuable natural history collections.

Keywords: Lepidoptera, SEM, *Suidasia*, dried specimens, mites

Introduction

Natural history repositories have documented biodiversity since their inception and now, due to loss of natural habitat, have become valuable resources for tracking these changes, often holding the only known specimens of threatened or little-known species (Shaffer *et al.*, 1998; Freedman, 2021). Yet despite this, government support for maintaining these repositories has decreased. Trained and enthusiastic replacements for retiring experts are few due to lack of opportunity caused by this lack of funding. The problem is critical in countries like India where environmental conditions, especially high humidity, speed up the deterioration of specimens. Trematerra and Pinniger (2018) mention many arthropods causing damage to museum specimens and suggested various preventive methods. Among these, astigmatan mites (Acari: Sarcoptiformes: Astigmata) are most important, with several species feeding on various stored products, including insect collections (O Connor, 2007).

The presence of live mites on dried insect collections is undoubtedly cause for concern. However, mites have formed numerous associations with insects and their dead bodies are often found still associated with museum specimens. In this manner, insect collections are rich resources for species discovery, and Lepidoptera are no exception, with numerous groups of mites found on moths. Larval Parasitengonina are most common (Felska *et al.*, 2018) but notable other groups include the otopheidomenines (e.g., Prasad, 1975, Lindquist *et al.,* 2020) and *Dicrocheles* (Treat, 1970), as reviewed by Treat (1975). However, the mite pests of stored products – which primarily comprise the Astigmata – are very rarely found on

Lepidoptera. This is especially true for any stage that is not a phoretic deutonymph, a life stage specifically adapted for transport on a carrier, usually an insect (Treat, 1975; O Connor, 2007). Thus, their presence is generally regarded as a contaminant: mites moving from the general environment onto dead insects. In this article we report and discuss our serendipitous discovery of mites from the eye cavity of the moth *Asota caricae* Fabricus,1775 (Erebidae; Lepidoptera).

Report

We were microscopically examining the compound eye of five lepidopteran species [*Asota caricae* Fabricius, 1775, *Daphnis nerri* Linnaeus (1758), *Micronia aculeata* Guenée, 1857, *Catopsilia pomona* (Fabricius, 1775) and *Euthalia aconthea* Cramer, 1779] as part of another study during August 2019. All the specimens (three to five per species) were examined destructively, spread and dried for a week following standard protocols (Krogmann and Holstein, 2010). The specimens were stored in insect boxes and transported over 277 km to Trivandrum from Thrissur (Kerala State, India). They were taken out in the SEM chamber at Sree ChitraTirunal Institute for Medical Sciences & Technology. None of the specimens showed any external signs of deterioration. For SEM analysis, the intact compound eyes were dissected out of the heads using a razor blade. The extracted compound eyes were pressed carefully over a stub with double sided tape. The stub was placed into the sample chamber in the SEM-EDX and pictures of the compound eyes at different scales and angles were taken.

The surface of the eye from all examined specimens appeared unbroken (Fig.1) but the inside of the eye from one *A. caricae* specimen showed at least eleven mites and clusters of what seemed to be eggs (Fig. 2 and 3). As the point of reference for identification was SEM images, only those identifying features presented clearly in the images could be considered. The mites are *Suidasia* (Suidasiidae), which have distinctive body ornamentation that is clearly visible in our SEM images (Figures 4-5). The dorsal body patterning suggests the species is *Suidasia nesbitti* Hughes, 1948. Other features for species identification are not visible (Hughes 1948, 1976; Fain and Philips 1978).

Discussion and Conclusion

After the serendipitous discovery of mites inside the eye of one specimen of *A. caricae*, other specimens of *A. caricae* were examined, but no other infestations were found. However, a single mite and a few Psocoptera (book lice) were observed from the external body surface of a freshly collected *A. caricae*. The discovery of book lice, as well as a mite, on the external surface suggests that the mites were already present prior to the insects being examined, and moved to these specimens as a fresh food source. However, one intriguing possibility is necromeny, a relationship where phoretic mites, instead of moving to new habitats, stay with their host until they die (e.g., Wirth, 2009; Badhran and Ramani, 2019). While we do not expect this to occur in *Suidasia*, the presence of necromeny in other Astigmata suggests that utmost care should be taken with insect specimens immediately after collection.

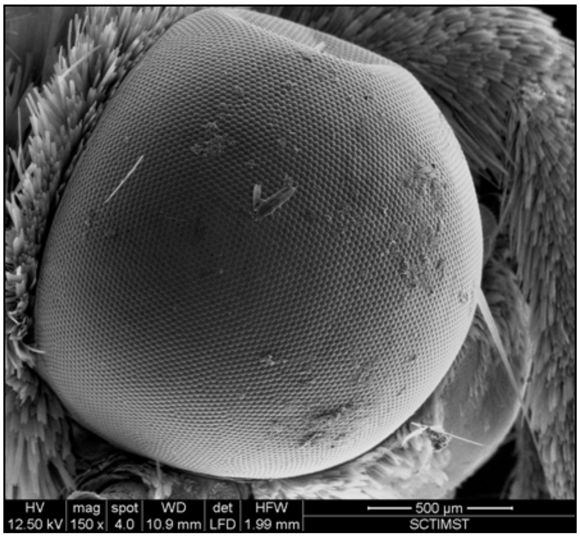


Figure 1. Unbroken eye surface of Asota caricae.

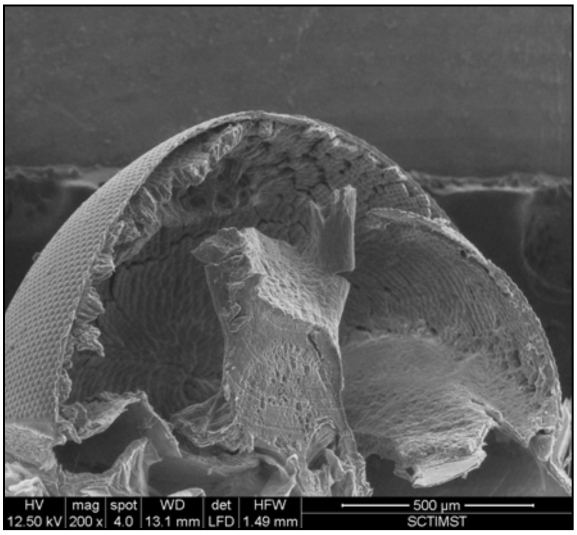
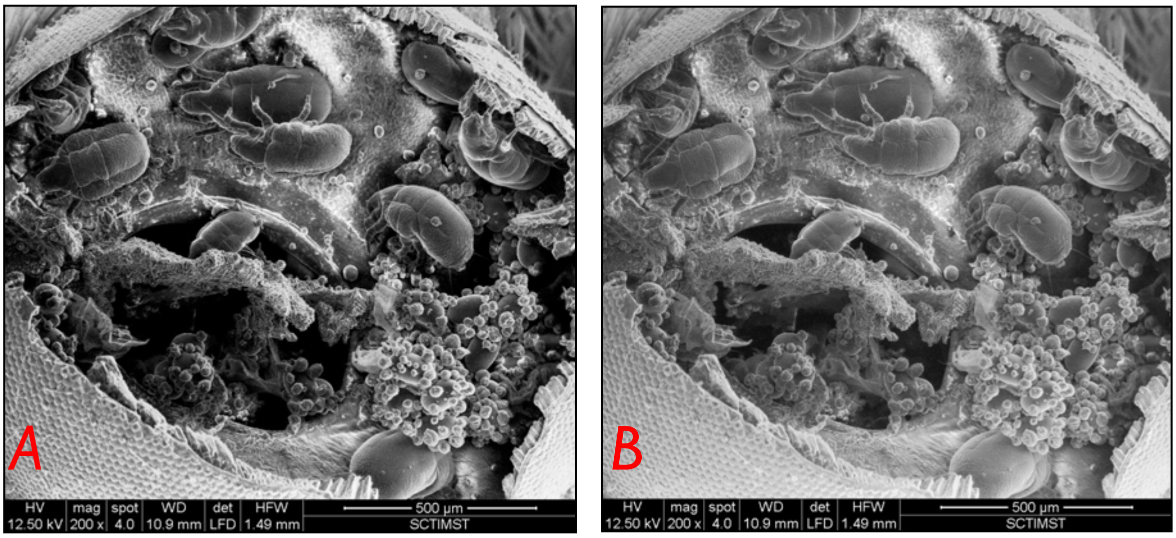


Figure 2. Eye cavity without mite infestation.



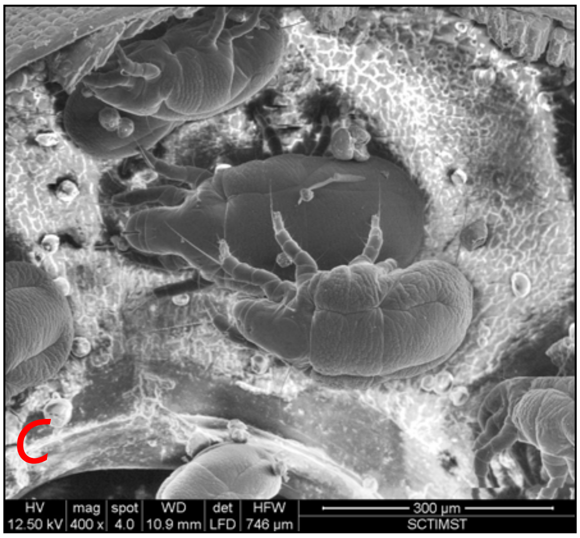


Figure 3. a, b and c: Eye cavity with mite infestation from different angles.

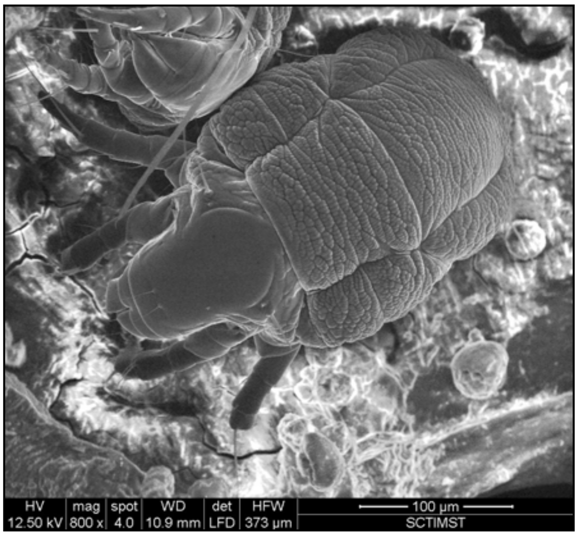


Figure 4. Eye cavity with mite infestation- dorsal view.

Suidasia species are mycophagous species with an astonishing range of habitats. While typically inhabiting a variety of stored products and peridomestic habitats, they have been found invading beehives and nests of solitary bees (*Xylocopa*), on rodents and bats, in bird quills, causing dermatitis in humans and even entering human ears (Fain and Philips, 1978; Koeniger *et al.,* 1983; Ho and Wu, 2002; Samung *et al.,* 2006; Klimov *et al.*, 2016). These mites also appear frequently on dead insects, such as dead mosquitoes (Fox 1950), wasps and beetles (Manson, 1973; OS, pers. obs.). Thus, *Suidasia* is a potential pest of museum collections as they show a remarkable ability to find and exploit recently killed insects. However, as they are mycophagous (Sinha, 1968), decreasing mite infestation requires limiting or eliminating fungal growth on drying insects.

Identifying infestations of mites in museum specimens can be difficult as they tend to target internal soft tissues, which can be completely destroyed, causing smaller specimens to decay or fall apart (Samsinak and Dlabola, 1980). Infestations are likely limited at first, but as life cycles are about two weeks and fecundity over 150 eggs per female (Chmielewski, 1991; Mercado *et al.*, 2001), mites can spread quickly through a collection. Thus, appropriate conditions in natural history collections, as well as treatment of specimens, is essential. Of these conditions, humidity control is paramount. *Suidasia* prefers humid environments (Hughes, 1976; Chmielewski, 1991) and many stored-product mites die below 70% RH (e.g. Sánchez-Ramos, 2007). Therefore, when specimens are stored in a dry environment, damage may be limited to the microclimate of the infested specimen. Furthermore, if the insects are dried quickly then the mites may not complete development. Regarding treatments, freezing specimens may work, but only when frozen for long periods, as most eggs survive at -40 °C for five hours (Edrees, 2014). Likewise, eggs show remarkable resistance to high temperatures (Edrees, 2014). Chemicals are also unlikely to be effective as mites can avoid contact by living within an insect's body. Therefore, we recommend movement of specimens to a dry environment soon after collection.

How did mites gain access behind the eye of a moth in a relatively undamaged week-old specimen? We presume these mites entered the body through natural openings (e.g., tympanal openings, spiracles, genital and anal openings) and therefore no obvious entry points are visible. Thus, infestations can be cryptic. Therefore, even if infestations are short-lived and do little damage, museum specimens may have cadavers of these mites within the bodies of pinned insects. If museum conditions cannot completely suppress fungal growth – especially in hot and humid tropical conditions – these mites could irreversibly damage valuable insect collections. We encourage collectors to move specimens to climate-controlled environments with humidities as close to 50% or below as quickly as possible and curators to show utmost care in taking in new insect collections.

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A closed case: safely displaying 1140 spirit preserved marine animals for a new permanent public gallery

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Abstract

Plymouth City Museum and Art Gallery (rebranded as The Box) began a 5 year redevelopment project in 2015. As well as a new public space outside, and a large extension to the main museum building, there would be 7 new permanent galleries. The new natural history gallery would display a range of different natural history collections, including over 1140 spirit preserved animals. This paper outlines the design process for the specialist case to safely hold this large number of specimens preserved in hazardous fluid. With no equivalent in any UK museum, the design relied upon several experts working closely throughout the whole process, and clear communication between different teams. The resulting case not only displays newly conserved spirit specimens, but has built in mechanisms to ensure that any hazardous fumes are removed from the case and not let into the gallery. This new display case allows visitors to see marine animals that they have never seen before.

Keywords: Display case, spirit preserved specimens, marine life, Conservation, health and safety

Introduction

In 2015, Plymouth City Museum and Art Gallery began work on a large project to expand the museum and redevelop the entire site. Combining the collections of the museum, the Plymouth and West Devon Records Office, the South West Image Bank, and the South West Film and Television Archives, the new building would be three times as large as the original museum. As part of the redevelopment, the museum was rebranded in 2018 as The Box, Plymouth to reflect the design of the new building (Freedman, 2021).

The new redevelopment includes 7 new permanent galleries, and 6 galleries for temporary exhibitions. The permanent galleries were designed using the collections from The Box, displaying art, film, archives, archaeology, social history, ethnography, and natural history. The new permanent exhibitions focus on Plymouth and the surround area linked to more global stories.

The completed natural history gallery displays 6948 specimens, including fossils, minerals, entomology, taxidermy, herbaria, skeletal material, and spirit preserved specimens (Figure 1). The key focus of this gallery is the environmental challenges that face our planet today. Sub fossil specimens discuss our recent past and extinctions. Entomology

Figure 1. The new natural history gallery at The Box, Plymouth. Displaying 6948 specimens, the gallery focuses on current environmental issues facing our planet today. (Photo Jan Freedman)

collections display the unique biodiversity of our planet, and how fragile this is. Herbaria specimens show the importance of plants to the entire ecosystem, whilst taxidermy and skeletal specimens focus on habitat loss. The mineral collections were used to discuss the geological history of the South West and the important mining heritage of the area. The spirit collections display the unseen diversity of marine life, looking at climate change, ocean acidification, and marine pollution.

Displaying such a diverse range and number of specimens required the construction of specialist showcases. Several individual cases were built into the walls to display collections, and two large cases were built in the centre of the gallery: one to display taxidermy, skeletons and minerals; and one designed to display 1140 spirit preserved specimens. These two large cases in the centre of the gallery were side by side, giving the appearance of one large case. This paper outlines the development of the spirit case, from conception to completion, and how to safely display such a large number of hazardous material for the public.

The spirit collection

The Box cares for over 4000 spirit preserved specimens. When the museum opened in 1910 it had acquired approximately 500 marine specimens preserved in specialist cuboid glass jars for display, known as battery jars (see Figure 6) (Freedman, 2012). The majority of these were local marine species that can be found off the Plymouth coast, along with a number of foreign amphibians and reptiles. In 2000, the museum was donated a substantial collection of approximately 3500 jars and associated archives, from the Marine Biological Association of the United Kingdom (MBA) (Freedman, 2012). Preserved in mainly Kilner jars, the majority of the specimens were local species which were collected to complement the study of species found in and around the Plymouth waters, known as the Plymouth Marine Fauna (Marine Biological Association, 1904; Marine Biological Association, 1931; Marine Biological Association, 1957). The collection includes many historically and scientifically important specimens as part of ongoing research at the MBA since it's opening in 1888. There are several collections from surveys, and a review of the collection in 2011 found one type specimen and two co-types (Freedman, 2011; Freedman, 2012). As well as the research potential with this collection, it offers a unique view into the rich marine life off the coast of the South West.

Gallery concept

The gallery was divided into three sections: Life in the Past (fossils and sub-fossil specimens), Life on Land (entomology, herbaria, taxidermy and skeletal specimens), and Life in the Sea (spirit preserved specimens). The focus of these sections was to use the collections to present the key messages of extinction, biodiversity loss, climate change, pollution, and habitat destruction. For the Life in the Sea section of the gallery, the history of marine science research through to modern day research was developed to present the history of marine science in Plymouth, and how marine scientists today are working on global environmental issues. The spirit collections were identified as a key part of this section.

With a large number of spirit preserved specimens in the collections, we wanted to display as many as possible, for two reasons. Firstly, we wanted the public to see these specimens on display rather than keep them in storage in order for them to appreciate the vast scale of the museum collections. Secondly, we wanted visitors to see the enormous diversity of life which is normally hidden beneath the waves, and how fragile it is. With adjacent displays highlighting the important marine science research that has, and is, being undertaken, the large display of marine creatures marries this section together: the visitors are able to see the animals that are affected by anthropogenic issues.

The cases for the redevelopment were designed by Meyvaert. Over 1000 spirit specimens would be displayed in the new spirit case, the largest jar holding 10 litres of fluid, and the smallest holding 10ml. This would be the largest number of spirit specimens on display in a museum in the UK. The design of this case required close collaboration between the curator, the conservator, Event Communication, Meyvaert, and an external consultant, CCTech. Colleagues at the Natural History Museum, London were consulted, based on their knowledge of cases for spirit collections which were built into the new Darwin 1 and Darwin 2 redevelopments.

The original designs for the case included shelving that was not fit for purpose. This early concept included glass shelves which were held by wires connected from the top of the case to the floor of the case. This would have not held the weight of the specimens so was changed to a strong aluminium frame with glass shelving placed in position.

There were going to be a large number of specimens displayed in this case. However, the intention wasn't just to fill the case with as many specimens as possible. The key message of this case was to show the variety of life that can be found under the coastal waters of the South West. This was planned using the case designs (Figure 3). Shelves were divided into sections to highlight main groupings of marine animals and a number of specimens within these groupings had their own individual labels to introduce the group of organisms (Figure 4). Using this process, specimens in the store were identified for display in each section based on the shelf height.

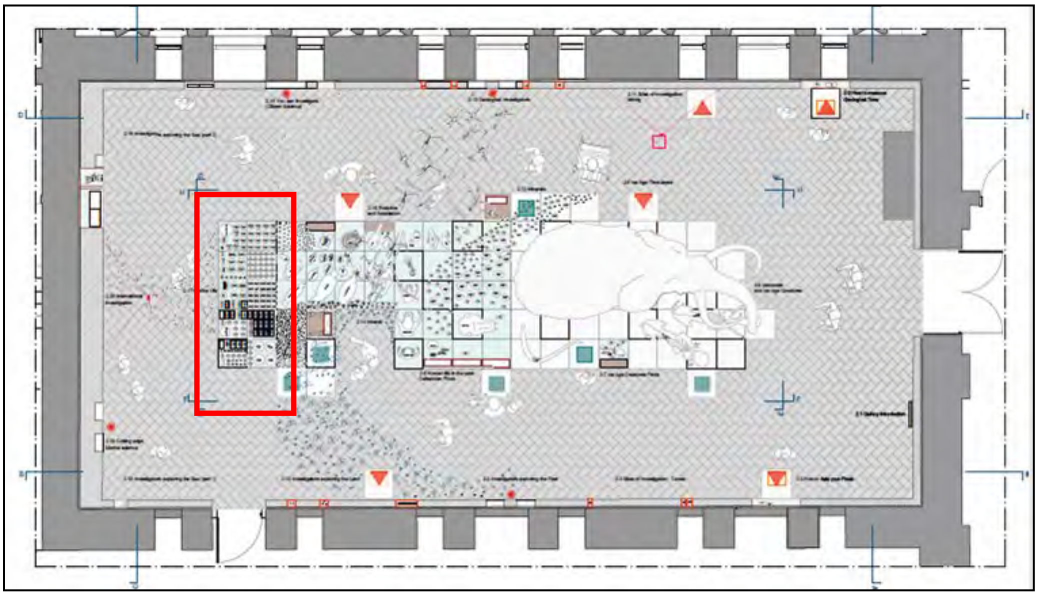

Figure 2. The gallery design from above, by Event Communications for the new natural history gallery in The Box, Plymouth. The case for the spirit specimens can be seen in the centre towards the left (highlighted in red).

Figure 3. The case design by Event Communications, showing the shelving layout which was used to create areas for different groups of marine organisms.

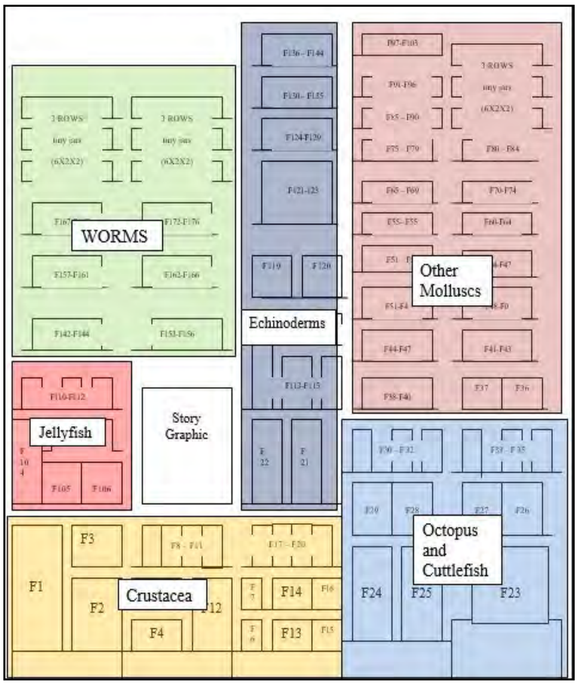

Figure 4. The sections for the front of the case showing the main groups of marine animals. The 'F' numbers were the curators' codes for the specimens which would be placed on the shelves. (Image Jan Freedman)

Spirit specimen conservation

The majority of the specimens in the collection are preserved in 4% formalin, with a smaller number in 70% Industrial Denatured Alcohol (IDA) in varying states of condition. All specimens that would be on display were to be stored in 70% IDA to reduce the risk to staff, and potential risk to visitors from any fume leakages. With the poor condition of the fluid, and being preserved in formalin, this meant that each specimen that was to go on display needed to undergo conservation treatment. The conservation work for each specimen was carried out in a fume cupboard, with staff wearing lab coats and disposable gloves. A risk assessment for the conservation work was undertaken prior to the work beginning.

Three types of conservation treatment were required for the specimens: rehydration, transferring from formalin to IDA, and changing specimens in discoloured alcohol into new alcohol. Dehydrated specimens were washed with 3% decon90™ and 97% deionised water to remove old and discoloured chemicals (Moore, 2006, *pers comm*). They were then washed with deionised water and fixed in 4% formalin for 24 hours, which ensured that the tissue within the specimens were held together (Stoddart, 1989; Moore 1999). Specimens were then placed into 30% IDA for one hour, 50% IDA for one hour, and finally 70% IDA as the final preserving fluid (Moore, 1999; Moore, 2006, p*ers comm*).

Formalin preserved specimens were washed with 3% decon90™ and 97% deionised water to remove the old and discoloured formalin (Moore, 2006, *pers comm*). They were then washed with deionised water, and placed into 30% IDA for one hour, 50% IDA for one hour, and finally 70% IDA as the final preserving fluid (Moore, 1999; Moore, 2006, p*ers comm*). Specimens which were in discoloured IDA, were washed with 3% decon90™ and 97% deionised water to remove any discoloured fluid (Moore, 1999). Specimens were then rinsed with deionised water, and then stored in 70% IDA (Moore, 1999; Moore, 2006, *pers comm.*).

The conservation for each specimen was carried out individually; each specimen was conserved in its own jar, there was no bulk conservation with several specimens in one jar. The majority of the conserved specimens were restored in new ground glass jars (Figure 5). These were sealed with petroleum jelly (Moore, 1999).

Although the majority of the jars were originally in Kilner jars or Danish jars, a number of square battery jars were also included in the display. These were not transferred into new ground glass

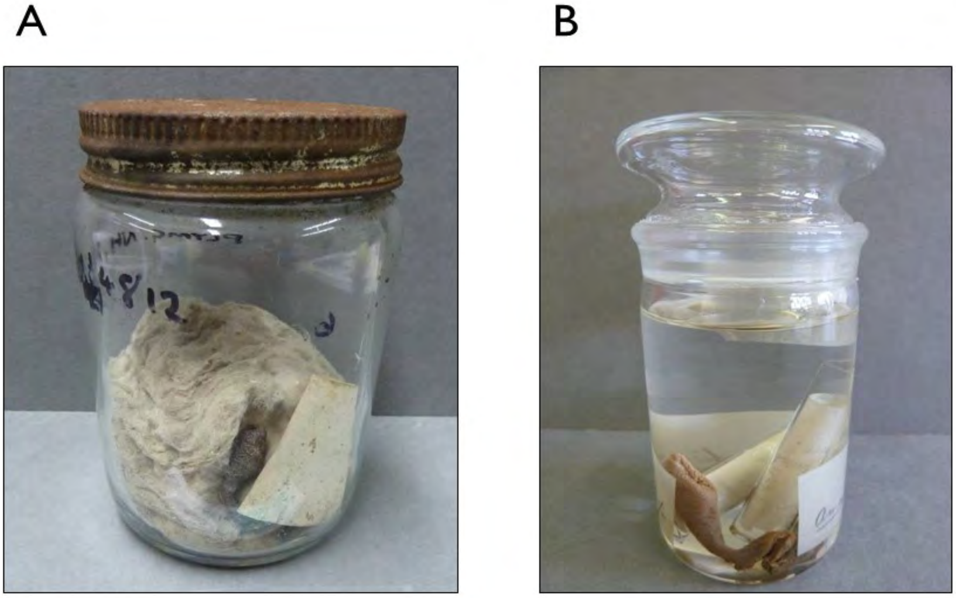

Figure 5. The type specimen of Amalosoma eddystonense Stephen, 1956 (PLYMG.NH.2000.1.4812) conserved prior to this conservation project. This example shows the standard that all the specimens on display would be from old Kilner or screw-lid jars to new ground glass jars. A. Specimen before conservation. B. Specimen after conservation treatment. (Image Jan Freedman)

jars, because of the display quality of the battery jars. The majority of these were particularly deteriorated with seals broken and paint on the back of the jars peeling off. All specimens were transferred into 70% IDA using the process above, and the jars were cleaned fully and any paint residue removed.

The decision to remove the paint was made by the authors after discussions about how the jars would work in the new case. The case was lit from the back, so any paint would have prevented the LED lights from lighting up the specimens. The lids were sealed with petroleum jelly, and white linen tape, moistened with deionised water, was used to seal the lids securely in place (Figure 6). Gelatine is normally used to provide a seal for battery jars (Moore, 1999), however, the time constraints on the conservation work made this method unmanageable. The case will be visually checked once every three months to monitor any dehydration within the jars and to monitor the seals around the battery jars.

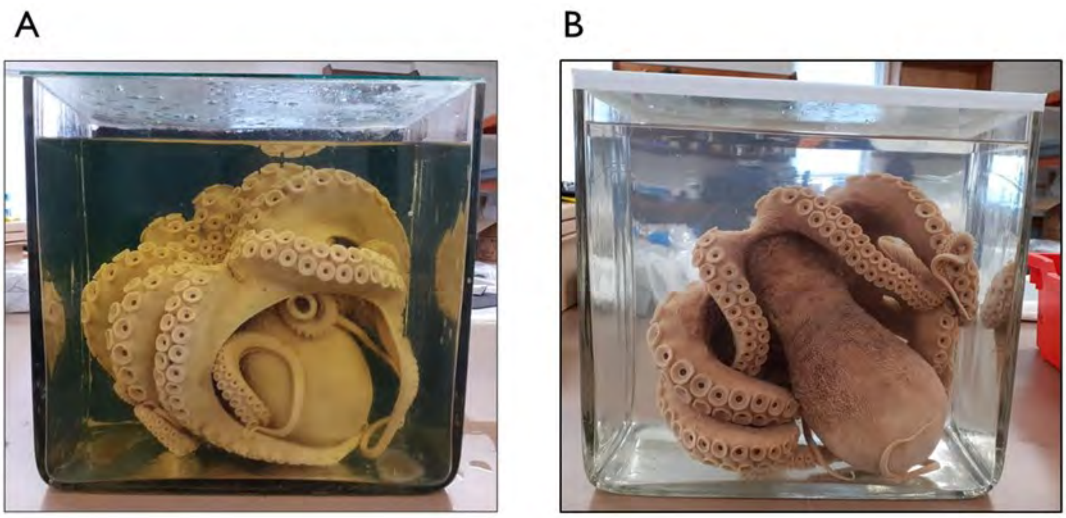

Figure 6. The common octopus (Octopus vulgaris Lamarck, 1798) in a square 'battery' jar (PLYMG.4601). A. Specimen before conservation. B. Specimen after conservation treatment. (Image Jan Freedman)

As the conservation work was carried out, all the information was recorded from each specimen, and updated onto the museum Adlib database. New labels were added to some of the jars, where the old labels had deteriorated, using cotton fibre Resistall paper and Pigma Micron permanent ink pens. A small label noting the conservation date and the preservation fluid was also added to each jar. A total of 1140 spirit preserved specimens were conserved for the new display.

A case for hazardous chemicals

The majority of the specimens in the collections at The Box were stored in 4% formalin. However, due to the hazard to human health associated with formalin, all specimens on display were transferred into 70% IDA and 30% deionised water prior to being installed. This would reduce the risk to staff installing and accessing the specimens, and reduce the risk to visitors in the event of any fumes being released.

IDA is a highly flammable liquid, with a flash point for 99% IDA of 14°C (MSDS, 2015), so several measures were taken to mitigate any fire risk. LED lighting was used within the large case which would light the specimens through the glass, with the power source safely outside the case. Plug sockets in the gallery floor were originally designed to be directly under the spirit case, and these were removed due to concerns of potential leaks and the fire risk. A small extractor fan was installed within the case. The fan is powered by a motor at the bottom of the case, which is raised above the floor and covered to protect it from any spillages. The extraction ductwork makes its way to the roof of the building where a larger fan extracts and expels fumes above the roofline. Small air openings with filters were included at the bottom of the case doors, to allow the fan to pull air in from the gallery and prevent the creation of a vacuum. A bund tray at the bottom of the case was also added, which would capture any fluid if any of the jars were to break. The tray is 30mm deep, and is angled for fluid to move to the centre where there are taps to safely empty the bund tray.

At the time of writing there is no environmental monitoring in the spirit case. The case is checked visually daily for any spillages, leaks, evaporation, or broken seals. The Building Monitoring System (BMS) monitors the environment within the gallery (a stable 18-20°C and 53-59% RH), and as the air supply to the spirit case is drawn into the gallery we expect that the conditions are the same. The extraction fan within the spirit case, along with the exhaust end of the ductwork are monitored during regular gallery and building checks. The Box is currently undertaking a project to develop a new store for the spirit specimens, and within these plans, a Volatile Organics Monitor with an alarm will be installed in the spirit case, as well as in the new spirit store.

Figure 7. The instillation of the aluminium frame carried out by staff from Meyvaert, with the completed shelves for the back and side of the case. (Photo Jan Freedman)

Installation of the case

Labels for the specimens were attached on the inside of the glass, and these had to be positioned and installed prior to any specimens in the case. The exact positioning of these labels was worked out by placing the specimens in the position on the shelves, and a copy of the label attached in the correct position on the outside of the case. The labels were then installed in the empty case, on the inside of the glass by Leach, the procured graphic design printers.

The case has two large glass doors at the front, which open fully outwards and to allow access. The design of the case meant that the shelving at the back and sides had to be installed first, and this was set up onsite by Meyvaert (Figure 7). Specimens were then transported from the store in lidded crates (Really Useful Boxes), with each specimen sealed in clear zip lock bags in case of any fluid leakage. A safe access route through the museum was created to ensure no obstacles or staff were in the way. Tables were laid out near the case, and the gallery was closed off to everyone except the curator and colleagues installing the specimens. The specimens were installed onto the glass shelves, with the extractor fan running. A ladder was used inside the case to install the higher shelves first.

The central shelving was installed once the rear specimens were on the shelves, carried out by Meyvaert under the supervision of the curator. The floor to the case was made from Corian tiles, which had to fit between the shelves. This was done alongside the installing of the next row of shelving. Specimens were then installed into the middle shelves. The final front floor panels and shelves were installed by Meyvaert, and the final specimens installed (Figure 8).

Summary

This new case designed for the spirit collections was not without complexities. It required close collaboration between the museum staff, the design company, the display case makers, the graphic installation team, and outside colleagues. This was vital because there were several challenges with such a large case with an enormous number of specimens containing hazardous fluids. It was vital that there was clear communication throughout the design process to

Figure 8. The completed spirit case, displaying 1140 marine specimens. (Photo Jan Freedman)

ensure that the case was designed to be accessible, safe, and visually stunning for the specimens. The team held several face-to-face meetings to discuss the requirements, and detailed drawings were assessed, and comments were fed back with recommendations for improvements. With input for several specialists from different areas, and good communication throughout the process, the case had no difficulties during instillation, and was built with the key safety elements to prevent risk to the visitors.

Displays in museums need to show the specimens for visitors to see them up close, and not just be a mass of specimens. This was a really important element to this display. Working closely with the case designs, the shelves were divided into groups so that they would be easily identifiable by the visitors, and the stories for each grouping was clear in the accompanying labels.

The largest challenge of this case was the installation of the specimens. This had to be planned to the jar. Each jar had a specific place on each shelf, and after conservation, they were labelled to the corresponding shelf. Safely transported in order, they could be installed by matching the label to the exact position on the shelf.

The resulting case displays 1140 spirit specimens from floor to ceiling. The visitors have the opportunity, many for the first time in their lives, to see marine life up close. Not just a crab or an octopus, but an enormous variety of marine animals showing the beautiful biodiversity of life that is hidden just beneath the waves.

Acknowledgements

Thank you to colleagues at Event Communications, Meyvaert, and Leach for the design and installation help for this case. A very special thank you to Jessica Viney, our work placement student who helped tremendously with the conservation work and the installation work for this case. Thank you to Clare Valentine at the Natural History Museum, London for her advice during the case designs. Thank you to the two reviewers for their useful comments which enhanced this paper.

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Ecologies of Display: Contemporary art, natural history collections and environmental crisis

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Abstract

This article explores the development and display of contemporary art in natural history collections as a way to engage audiences with environmental concerns at a time of ecological crisis. It contextualises this field of practice within recent art and curatorial history and explores this work in relation to long-term programmes of contemporary art in the context of natural history collections at the Natural History Museum, London, Museum für Naturkunde, Berlin, and the Horniman Museum and Gardens, London. I observe the possibilities this work presents for encouraging engagement with ecological distress through exhibitions and observe the challenges inherent to this curatorial work.

Keywords: Contemporary art, natural history, exhibitions, display, environmental change

Introduction

This article explores the development and display of contemporary art in the context of natural history collections as a generative way to engage audiences with environmental concerns at a time of ecological crisis. Since 2019, UK museums across the sector have been declaring a climate crisis and ecological emergency (for instance Natural History Museum, 2020 and Horniman Museum and Gardens, 2019). This followed in the wake of the 2018 rise of Extinction Rebellion and the School Strike for Climate along with wider public concern and awareness about climate breakdown (*Engaging the Public on Climate Risks and Adaption*, 2021). There have also been several significant interventions in the cultural sector responding directly to ecological crisis. For instance, Culture Declares Emergency was initiated in 2019 as an international movement of individuals and organisations in the art and museum sector declaring climate and ecological emergency and ICOM's 2019 resolution 'On Sustainability and the Implementation of Agenda 2030' sought to mobilise the UN's 17 Sustainable Development Goals within the museum sector (see McGhie, 2020: 659-660). The Museums Association recently called for museums to maximise sustainability, raise awareness and champion change about the ecological state of play (Museums Association, 2021) and climate crisis was a significant theme in the organisation's annual conference in 2021. In addition, a body of academic literature has been emerging detailing the challenges and opportunities of engaging visitors with climate change and its effects in museums (for instance, Cameron, 2011; Cameron and Neilson, 2014; Newell, Robin and Wehner, 2016; Lyons and Bosworth, 2019; Serafini and Garrard, 2019; Harrison and Sterling, 2021). This activity provides the backdrop to an increased momentum in museums tackling this pressing issue on gallery.

Natural history collections are well placed to address ecological crisis through displays and exhibitions due to the types of collections in their care and to date, activity in response to this issue has been curatorially wide ranging. Approaches have spanned large scale masterplan redisplays, like the 2017 replacement of Dippy the Diplodocus with Hope the Blue Whale at the Natural History Museum, London, to place an anthropogenic extinction narrative centre stage (Syperek, 2020; Lowe *et al*., 2020), to more modest but no less effective interventions in existing displays of historical taxidermy such as *Extinction Voices* (2019) at Bristol Museum and Art Gallery, which shrouded extinct and endangered species in mourning veils to raise awareness about the threats facing wildlife today, such as poaching. These different approaches, however, have been united by placing human activities at the heart of environmental breakdown.

The Natural History Museum, London, recently framed ecological crisis within the Anthropocene, a term proposed by the Nobel Prize-winning atmospheric chemist Paul Crutzen and the biologist Eugene Stoermer in 2000 as the name for a new epoch to replace the Holocene, in recognition that evidence of human activity is traceable in the geological strata of Earth (Crutzen and Stoermer, 2000). As the feminist philosopher, biologist and science and technology scholar Donna Haraway has poetically stated: 'the effects of our species are literally written into the rocks' (Haraway and Kenney, 2015: 259). But more than this, the Anthropocene has become somewhat of a 'charismatic mega-category' (Reddy, 2014), gesturing to anthropogenic planetary change beyond its geological origins to provide an ecological rallying point for creative practitioners and academics from the arts, humanities and social sciences, where it has gained traction and precipitated extensive activity in these fields. It has been observed that the Anthropocene appears to have 'captured an *intellectual zeitgeist*' that 'is proving extremely generative of conversation and creativity' (Lorimer, 2017: 121-122). It follows that the Anthropocene concept has provided a frame, if not always the name, for a number of recent ecologically orientated exhibitions. The Natural History Museum, London, has recently engaged visitors through 'Anthropocene' titled webpages featuring articles on biodiversity loss, climate change and plastic pollution, as well as the evolving exhibition *Our Broken Planet: How We Got Here and Ways to Fix It* (2021), staged to coincide with COP26 to address the ways humans have impacted the natural world. Such initiatives foreground the various ecologies of humans and other lifeforms inherent to climate crisis, presenting complex entanglements of nature and culture, or naturecultures (Haraway, 2003), and offering a site where museum professionals and the public can consider and reflect on various environmental issues in the past, present and future.

Another approach used in natural history collections to address the anthropogenic threats facing the planet is the development and display of contemporary art. As a discrete field of artistic and curatorial practice, this work has taken form as interventions, commissions, collaborative projects and temporary exhibitions, as well as many instances where artists have worked behind the scenes of the public galleries, engaging with collections, institutional histories and research undertaken on-site by museum scientists. Much of this work has occurred as one-off projects and a host of examples could be cited to demonstrate the proliferation of this field of practice in natural history collections around the UK, Europe and North America. However, it is significant that there have also been some long-term contemporary art programmes running in natural history collections, including at the Natural History Museum, London, where there was a dedicated curator of contemporary art between 2005-2013, Museum für Naturkunde, Berlin between 2014-2018, and the Horniman Museum and Gardens, London, particularly since 2019 when the museum declared a climate emergency. That these major museums embedded this type of activity into their programmes on a long-term basis testifies to a recognition of the generative role that contemporary art can play in this context. It is examples of work about ecological crisis from these more sustained programmes of activity that form the focus of this article to investigate the opportunities presented through an ongoing commitment to these necessarily collaborative and interdisciplinary curatorial practices.

This text is informed and guided by my disciplinary perspective as an academic art historian, so while museum professionals might anticipate more reliance on visitor evaluation here – an important part of museum work – my analysis is instead visually, theoretically and historically situated. After historicising this field of artistic and curatorial activity and establishing its ecological potential through an engagement with theoretical literature, I examine a series of case studies from the institutions identified above and evaluate the possibilities and limits of this work when it comes to addressing climate crisis. First, *The Ship: The Art* *of Climate Change* (2006) at the Natural History Museum, London, is considered to explore the possibilities this exhibition offered for raising awareness about ecological crisis and expanding audiences at a poignant moment, when climate change was – as is the case today – prominently in the public eye and under the media spotlight. Next, A.K. Dolven's intervention *echo echo* (2015), commissioned as part of the Art/Nature programme at the Museum für Naturkunde, Berlin, is examined to reveal how this project functioned on multiple levels by creating a new artifact for the collections, fostering collaboration between an artist and a museum scientist, enlivening a permanent collections display and, moreover, rendering the anthropogenic effects impacting wildlife and habitats tangible in the exhibition space. Finally, this article considers the contemporary artist Sonia Levy's work produced behind the scenes at the Horniman Museum and Gardens, London. Levy's *For the Love of Corals* (2018) took the institution's globally significant coral conservation research outside of the aquaria to engage audiences in ecological issues in other contexts. It also provided a chance to visualise corals in ways that might promote an ethic of care and a sense of responsibility towards the natural world amongst viewers.

A recent art and curatorial history: Contemporary art in natural history collections

The development and display of contemporary art in the context of natural history collections represents a distinct field of artistic and museological activity with a recent art and curatorial history, yet to date there are relatively few texts examining this work exclusively (Arends, 2009a; Arends, 2020; Hermannstädter, 2019; Lange-Berndt, 2014). This practice can be seen to emerge from both the SciArt programmes that gained momentum in the UK in the 1990s with the aim of fostering collaboration between artists and scientists, as well as from the practice of commissioning and displaying contemporary art in non-art museums. While there are examples such as the Imperial War Museum's artist residency programme initiated by then Keeper of Art Angela Weight in the 1980s (Moriarty and Weight, 2008), this work also gained pace in the 1990s, with artworks now having been presented in collections ranging across anthropology, social history, science, medicine, historic houses as well as natural history. In 1994 the Arts Catalyst was established with the express aim of commissioning new works that traversed the arts and sciences and in 1996 Wellcome Trust's sciart programme was established to support partnerships across these two disciplines to result in numerous collaborative projects (see Glinkowski and Bamford, 2009 and Arends and Thackara 2003 for more on Wellcome's sciart programme). Both of these initiatives resulted in collaborations between artists and natural history museums. For instance, Arts Catalyst worked with the artist Jan Fabre who produced *A Consilience* (2000), a film developed and displayed during a residency at the Natural History Museum, London. The film showed the results of a collaboration with museum entomologists, who feature dressed-up as insects and performing their creatures of study. In addition, Wellcome Trust sciart funding supported the British artist Mark Fairnington, who carried out a residency at the Oxford University Museum of Natural History between 1999-2002, culminating in the exhibition *Dead or Alive* (2002) at the same institution. This exhibition presented Fairnington's paintings of preying mantis and treehoppers that were produced during a long-term collaboration between the artist and museum entomologist Dr George McGavin, who studied these species together during fieldwork in Belize (Arends and Thackara, 2003; Ede, 2005: 168-170; Fairnington and Gisbourne, 2002).

It has now been thoroughly examined in the literature that the presentation of contemporary art in non-art museums presents various possibilities for expanding audiences, reinvigorating displays, reinterpreting collections, performing institutional critique, fostering collaboration across disciplines, engaging visitors in multisensory ways and activating the emotions (for instance Arends, 2009a; Arends, 2020; Barrett *et al.*, 2021; Arnold *et al.*, 2020; Bencard, Whiteley and Thon, 2019; Carroll La, 2011; Cass, Park and Powell, 2020; Masset, 2019; Putnam, 2009; Redler Hawes, 2010; Robins, 2013; Rossi-Linnemann and de Martini, 2020; Wade, 2020; and Wade, 2021). The art education scholar Claire Robins has observed that 'there is a growing awareness that visual, affective and intellectually engaging aspects of artists' interventions may encourage new experiences for audiences so as to re-conceive and reconfigure museums' (Robins, 2013: 1), offering transformative possibilities that can contribute to reshaping the museum experience, as well as museum practices, in the face of ecological distress today. In the context of collections and museums with a science focus, Camilla Rossi-Linnemann and Guilia de Martini have suggested that this work can also aid communication and interpretation, educate visitors and prompt discussion (Rossi-Linnemann and de Martini, 2020: 13). The potential engagement opportunities of such work are well established. Nevertheless, the presentation of contemporary art in non-art museums has equally faced criticism for being inaccessible to visitors or even overlooked by those who may not be accustomed to engaging with artworks and who might need further interpretation to make sense of them (Robins, 2013: 9-10; Redler Hawes, 2020: 82 and 87). Such cross disciplinary endeavours present challenges and natural history collections are far from being immune from this risk. Some of the ways this challenge has been addressed are examined through the case studies that follow.

A curatorial approach that entangles nature and culture is fruitful as a basis for considering ecological crisis through display and exhibitions, presenting the reality that all life on Earth is interconnected. It is important to clarify that the use of the term curatorial here refers to practices of exhibition-making, recognising that natural history curators are frequently collections-focused with separate exhibition departments often tasked with delivering exhibitions in natural history museums (Lowe *et al.*, 2020). The development and display of contemporary art in natural history collections provides a way of bringing nature and culture into relation to provide opportunities for creating what I have referred to elsewhere as 'ecological exhibitions', which present ecological content and also work in ecological ways (Wade, 2020). If ecology is understood in the sense coined by Ernst Haeckel in the 1860s ('oecologie') as the dynamic relationships between beings, things and their surroundings (Arnold, 1996: 3), when applied to exhibition-making it can bring issues such as climate change, habitat loss and anthropogenic impacts on wildlife to the fore through an approach to display, content and interpretation that brings things, beings and disciplines – including objects, artworks, artefacts, specimens, humans and nonhumans, art and natural history – into relation with one another to perform what the museum studies scholar Fiona Cameron has called 'ecologizing experimentations' (Cameron, 2015, see also Wade, 2020 for an analysis into this concept in relation to Mark Dion's *Oceanomania* cabinet of curiosities at the Musée Océanographique de Monaco). Cameron observed that the dualistic principles that underpin the modern museum as an institution (i.e. one space for natural history collections and another for art) do not acknowledge the inherent entanglements of humans and other lifeforms that are so fundamental to thinking through the current ecological crisis (Cameron, 2015: 18). Cameron proposes ecologizing experimentations as a way to resist binary thinking and produce more equitable, inclusive and interconnected displays for these ecologically troubled times (Cameron, 2015: 29). This approach presents possibilities for decentring the human to bring all earthly life into the sphere of care and consideration, diluting the sense of human exceptionalism that was responsible for creating the chaos of climate crisis in the first place. As theorist Eva H. Giraud recognised, 'Narratives of entanglement have […] proven important in implicating human activities in ecologically damaging situations and calling for more responsible relations to be forged with other species, environments, and communities' (Giraud, 2019: 1).

While Giraud rightly observes that simply acknowledging these entanglements is not sufficient to respond to the anthropogenic threats facing the planet (Giraud, 2019: 7), it is an approach that can be used productively by museums to engage visitors with issues pertaining to the current ecological crisis. As a curatorial strategy it also facilitates interdisciplinary modes of exhibition-making in which the arts and natural sciences can be brought into relation with one another in new and imaginative ways. This is particularly important given that it has recently been observed that art 'holds the potential for meaningful interdisciplinary and experimental research […] which excels in […] making climate breakdown meaningful, affective, legible, and politically urgent' (Demos, Scott and Banerjee, 2021: 8). When such an approach is realised through the development and display of contemporary art in the context of natural history collections, it presents possibilities for fostering collaboration between museum professionals in different types of institutions, expanding museums' potential visitors by engaging both arts and science audiences, as well as rendering ecological crisis emotive, tangible and, ultimately, actionable.

Natural History Museum, London's Contemporary Art Programme: *The Ship: The Art of Climate Change* (2006)

In the UK, the Natural History Museum, London, can be seen as somewhat of a vanguard in the presentation of contemporary art in natural history collections developing a number of exhibitions over the years. These include the aforementioned *A Consilience* (2000) by Jan Fabre, curated externally by the art organisation Arts Catalyst, Mark Fairnington and Giles Revell's *Fabulous Beasts* (2004), which presented largescale photography and photorealistic paintings of insects and James Mollison's photographic portraits of apes in the exhibition *Face-to-Face* (2005), programmed by the learning department. All of these exhibitions occurred before the appointment of a dedicated curator of contemporary art, Bergit Arends, at the museum between 2005-2013, which signaled the museum's commitment to incorporating contemporary artistic activity on a long-term basis and facilitated the delivery of a ten-year programme of art and science exhibitions that were at the heart of the funded redevelopment of the Jerwood Gallery. A number of high-profile commissions, collaborations, residencies and exhibitions followed in the wake of Arends' arrival, including Mark Dion's *Systema Metropolis* (2007) (Arends, 2019), Tessa Farmer's *Little Savages* (2007) (Farmer and Kaplan, 2008 and Lange-Berndt, 2014), the group show *After Darwin: Contemporary Expressions* (2009) (Arends, 2009b), Lucy and Jorge Orta's *Amazonia* (2010) and then the International Artist Research Residency Programme (2010-2012) (Arends, 2020).

While the contemporary art programme came to a close in 2013 as a result of cuts to funding, an enduring legacy can be found in the museum's Treasures Gallery where Tania Kovats's *Tree* (2009) is installed in the ceiling (Arends, 2009c). This was the museum's first permanent installation of contemporary art, commissioned to mark the bicentenary of the birth of Charles Darwin and the 150-year anniversary of the publication of *On the Origin of Species by Means of Natural Selection* (1859). In more recent years, contemporary art has featured in some of the museum's temporary exhibitions, for instance Heather Peak and Ivan Morison's sculptural installation *Cetaceans* (2017), which was presented in *Whales: Beneath the Surface* (2017) and there is also an ongoing NHM art-science interest group run by staff at the museum ('Art and Science at the Museum').

While many of the artworks commissioned and displayed in the Natural History Museum, London, have related to ecological concerns, the museum explicitly addressed environmental crisis through the presentation of *The Ship: The Art of Climate Change* (2006). The show was the result of a partnership with Cape Farewell, an arts organisation founded in 2001 by David Buckland as a cultural response to climate change (capefarewell.com). Between 2003 and 2005, Cape Farewell ran three expeditions to Spitsbergen where artists, scientists and educators journeyed to experience climate change in the arctic first-hand, making work in response to what they found there (Buckland, 2006: 6). *The Ship: The Art of Climate Change* was one of a series of exhibitions presenting the resulting works which took shape in wide-ranging media, including dance, photography, film, sculpture and installation. Iterations of the show subsequently travelled to the Liverpool Biennial of Visual Art and Sage, Gateshead in 2006, with other works presented at the Eden Project, Cornwall in 2007. The partnership between Cape Farewell and the Natural History Museum, London, was therefore unique in the exhibition's run for bringing an art audience into a natural history museum and engaging existing natural history museum visitors with contemporary art, thereby expanding the potential audiences for art and natural science alike. Significantly, the partnership also resulted in new commissions for the exhibition.

Given Cape Farewell's aim and the artists' direct engagements with climate breakdown, the exhibition presented content that was explicitly ecological (i.e. focussed on climate change and its effects) but through artistic, rather than scientific means. In the exhibition's press release it was observed how the exhibition sought to 'use the creative vocabulary of art rather than science, to raise an awareness that everyone individually can help alleviate the impacts of climate change', pointing to an explicit environmental objective behind the exhibition (Cape Farewell, 2006). This makes *The Ship: The Art of Climate Change* an early example of the sort of ecological exhibition-making described earlier, in which contemporary art is presented in natural history collections to draw attention to environmental breakdown specifically. In the same way that exhibitions about ecological issues are taking place today in a landscape where there is wide public and media attention around the subject of environmental crisis, this was true in 2006 when *The Ship: The Art of Climate Change* opened its doors. This was the same year that *An Inconvenient Truth* (2006), a documentary film that charted then Vice President Al Gore's efforts to raise awareness about global heating, grossed almost $50 million at the box office testifying to the mass appeal of this subject. It was also the same year that the renowned *The Stern Review on the Economics of Climate Change* was published, which gained extensive media coverage in its wake (Hilty, 2006: 11). The exhibition was therefore timely, coinciding with this wider shift in public recognition of climate change and its effects and able to harness this popular interest.

There were ultimately 108,827 visitors to this free entry exhibition (Hilty, 2006: 37), which served as a launchpad for further ecologically themed events at the museum, including a Climate Summit for 16-18 years olds attracting some 800 participants, as well as acting as a testing ground to establish audience interest in art/science projects. Free entry removed any financial barriers to accessing the exhibition, making it more likely that visitors already at the Natural History Museum, London, might attend as part of their visit. Nevertheless, a small evaluation of the exhibition revealed that half of respondents felt that they did not understand the exhibition and wanted more interpretation to make sense of it (Dawson, 2006: 9), gesturing to one of the potential difficulties in engaging visitors with contemporary art in the context of natural history collections where audiences may be unaccustomed to encountering artworks. The Natural History Museum, London, appeared to have recognised this challenge. It provided further information in the form of an exhibition newspaper that could be purchased for £1 that introduced some of the artists and scientists who had taken part in Cape Farewell's expedition in an accessible way and provided tips about the measures that visitors could take themselves to help reduce their own carbon footprint at home (Paterson 2006).

This evaluation response, however, suggests that visitors had expected factual information to be the key out-take from an exhibition in this context, overlooking the emotional and affective possibilities that encounters with contemporary art can provide here. One of the works in the exhibition was Ackroyd and Harvey's *Stranded* (2006) (Figure 1), a minke whale skeleton encrusted with crystals. The artists were drawn to make this work as a 'memento mori for our times' after seeing whale bones littering the arctic landscape during their expedition (Ackroyd and Harvey, 2006: 110). The resultant spot-lit installation appeared both beautiful and poignant, this sparkling cetacean skeleton recalling both the arctic ice and valuable jewels to become fragile and precious at the same time, evoking both sorrow and wonder through its glittering form. The art curator Greg Hilty observed the power that emotional responses to ecological distress can have when it comes to changing attitudes (Hilty, 2006: 10). In a recent study to analyse the potential of artworks presented as part of ArtCOP21 in Paris to raise awareness about climate change, the authors observed that '[s]ome researchers suggest that a solely fact-based approach to communication will not lead to behavioral change and is therefore not enough to raise public awareness and create engagement' (Sommer and Klöckner, 2021: 60).

The works in *The Ship: The Art of Climate Change* provided opportunities for activating visitors'

Figure 1: Ackroyd and Harvey, Stranded (2006). *Minke whale skeleton 6m long, aluminium potassium sulphate crystals. Commissioned by the Natural History Museum, London and Cape Farewell. Supported by the Cetacean Stranding Programme. Sculpture is exhibited with 17min. film documenting flensing process.*
Image © Ackroyd & Harvey.

emotions in response to the subject of climate change towards better raising awareness. Speculating on what the arts can do in times of climate breakdown, Demos, Scott and Banerjee suggest that they provide 'a vital site of intervention, complementary and alternative to the earth sciences, engineering, design, and economics, which have popularly defined climate-change discourse and policy' (Demos, Scott and Banerjee 2021: 1). Artworks can provide a different way into thinking through and responding to ecological issues, one that might activate the emotions in enabling ways, generating questions rather than necessarily providing answers and occasioning new lines of inquiry.

Art/Nature. Artistic Interventions at the Museum für Naturkunde Berlin, 2014-2018: A.K. Dolven, *echo echo* (2015)

Between 2014-2018, the Museum für Naturkunde, Berlin, ran the programme Art/Nature: Artistic Interventions at the Museum für Naturkunde Berlin, funded for the period by the German Federal Cultural Foundation. This international project involved a series of invited curators commissioning contemporary visual artists, sound artists and writers to make work in response to the museum, its collections, displays, science and histories. The work was presented amongst the permanent displays in a series of four separate interventions throughout the duration of the project. The programme resulted from the museum's aim to open the institution out to different disciplines, promote transdisciplinary dialogue and attract new visitors to create 'an experimental space for the interaction between art, museum practices and scientific research in order to establish new perspectives on nature and museum culture' (Hermannstädter, 2019: 11). The programme was a cross disciplinary and collaborative endeavour from the outset, with natural history museum scientists and curators working alongside art curators and practitioners, learning more about how one another worked along the way. Recognising the diversity of visitors who would encounter this work, an audience evaluation programme accompanied each of the four rounds of interventions so that the museum might implement changes as the project progressed to better support audiences in their engagement with this work. By the last iteration of artist interventions, audience evaluations signaled that 95% of visitors wanted the programme to continue (Hermannstädter, 2019: 15), suggesting it became a well-received and well-established part of the museum's offer.

The interventions tackled a number of topics and took wide ranging forms. Over the project, eleven interventions were commissioned of artists and writers including Sabine Scho & Andreas Töpfer, A.K. Dolven, Saâdane Afif, Serotonin, Fernando Bryce, Monika Rinck, Klara Hobza, Ulrike Haage, Elizabeth Price, Mark Dion and Assaf Gruber. Their interventions spanned the spectacular to the subtle, impacting the surrounding natural history displays in different ways. The Norwegian sound artist A.K. Dolven's intervention *echo echo* comprised the two-part sound work *sound outside outside the window* (2015) which, as well as a sound installation in the Hall of Birds, included a field recording of arctic cod mating that was installed in a large sculptural installation of preserved specimens of fish and other creatures at the museum, known as the Wet Collections. This work functioned on multiple levels and facilitated various levels of engagement with the museum, its staff and its visitors. Significantly, it also prompted the consideration of ecological concerns in the context of this museum.

The work was made through a collaboration between the artist and the museum biologist Karl-Heinz Frommolt who planned and carried out an expedition to capture the audio of a species currently not represented in the museum's Animal Sound Archive. As a result, the artwork produced a new artifact for the museum's collections in the form of an audio file that became part of the institution's archive. During the resulting exhibition, the sound piece was installed in the Wet Collections, a sculptural glass cube containing the museum's spirit collection (Figure 2). Despite its impressive display in a dramatically illuminated modernist glass cube, this collection comprises a repetitive series of fish and other creatures in spirit jars. Fish find it hard to compete with dinosaurs in natural history museum displays. They are often small, harder to preserve and relatively ordinary in comparison to the superlative specimens favoured by many museum audiences. This was amusingly highlighted through the efforts of the curator Mark Carnell in his entertaining blog 'Underwhelming Fossil Fish of the Month', which aimed to increase engagement with these less charismatic, but no less important, museum fish specimens at the Grant Museum of Zoology, London. As Carnell (2018) noted, 'not every museum specimen can be the first, last, oldest, biggest or nicest smelling […] it's important to take some time and space to think about the mediocre'. While these lifeless, faded spirit jar specimens possess an allure through their cumulative presentation in the spectacular design of the Wet Collections display, individually, they are rather unremarkable, perhaps even ugly, and therefore challenging to engage audiences with. This may have been the reason behind the dramatic, sculptural response taken by the Museum für Naturkunde which made the decision for its research collection of spirit specimens to be shown in-use by scientists through the glass walls of this display. A.K. Dolven's audio intervention added a multisensory and multimedia layer to this display during its installation, providing a further way to enliven this collection, returning the sounds of the sea to the specimens of fish on display to evoke their wider habitat (A.K. Dolven in Hermannstädter, 2019: 71).

As well as fostering collaboration between an artist and a scientist and adding a multisensory layer to existing displays to enhance visitors' engagement with the collection, this work also drew attention to ecological issues. The curator of this intervention, Gaby Hartel, recognised that during their field work the artist and scientist captured the sound of the cod, but also caught some 'acoustic "bycatch"' (Hermannstädter, 2019: 70). In addition to the sound of the fish mating, the recording documented the sound of the vulnerable cods' habitat. This included the ambient sounds of the surrounding sea and also the impact of human activity on the oceans' audio ecosystem, with motors of boats being audible on the sound file. The audio drew attention to one way that human activity is impacting habitats to affect the lives of marine species, thereby making manifest the inherent entanglements of humans and other species in the ecologies of the Anthropocene. Dolven and Frommolt may not have set out to make work about the impacts humans are having on wildlife and ecosystems, but their work drew attention to the ecological reality that everything is interconnected, recalling the eco-theorist Timothy Morton's stance that being ecological does not necessarily require any special effort, because humans are always already inherently enmeshed with other lifeforms (Morton, 2018).

One of the challenges of communicating ecological issues is finding effective ways to represent them. The long-term effects of climate change unfold over time, making it hard to grasp their urgent reality. Contemporary art can help to render ecological issues tangible, visible and, in this case, audible by situating them in space and time. Indeed, it was the creatures out of sight beneath the surface of the sea that A.K. Dolven was able to bring into the very human sphere of the museum space though this sound installation.

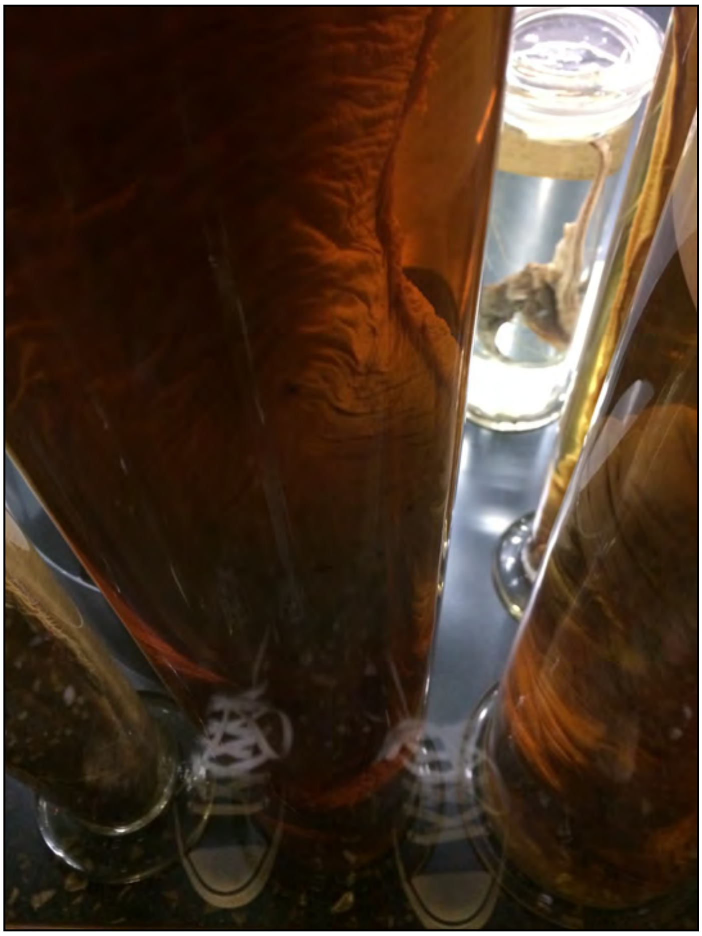

Figure 2.
A K Dolven,
echo echo
sound outside
outside the window
(2015)
Wet collection, Naturkundemuseum, Berlin. Curator: Gaby Hartel. Photocredit: Studio A K D

Horniman Museum and Gardens, London: Sonia Levy, *For the Love of Corals* (2018)

In recent years, the Horniman Museum and Gardens has presented a number of contemporary art exhibitions. This activity has increased momentum and taken a more explicitly ecological turn following the museum's declaration of a climate and ecological emergency in 2019 and the announcement of its Climate and Ecology Manifesto in January 2020. Recent exhibitions have included *MELTDOWN: Visualising Climate Change* (2019-2020) a touring photographic exhibition initiated by the climate change charity Project Pressure to document changing glaciers, Claire Morgan's *As I Live and Breathe* (2019-2020), which drew attention to plastic pollution in urban environments, Helena Hunter's *Falling Birds* (2020-2021), the result of the artist's Artquest Research Residency at the museum, which explored avian extinctions, and the commissioning of Jasmine Pradissitto's *Bee Girl* (2020), a sculpture which aims to absorb car pollution from nearby busy roads so that bees might more readily locate the flowers in the gardens. Whilst there is no such explicitly formalised programme with a fixed timeframe such as Berlin's Art/Nature programme, this expansive activity expresses a commitment to this field of practice in ongoing ways and the Horniman Museum and Gardens' naturalcultural constitution, with natural history and anthropological collections, as well as live specimens on display, makes it ideally placed to marry art and the natural sciences in ecological ways.

In addition to making work in response to the collections, artists have also made work about the research taking place behind the scenes of the public displays. The Horniman Museum is home to an aquarium where a pioneering research programme, Project Coral, has developed methods to predictably spawn coral in captivity. Coral reefs are at risk from rising sea temperatures, ocean acidification and pollution with widespread bleaching events threatening these significant biodiverse ecosystems. The research underway at the Horniman Museum aquarium works towards conserving corals and coral reefs in the wild through work with corals in captivity, presenting possibilities for breeding programmes that might help repopulate reef habitats. In a move predating the artistic activity at this institution outlined above, the French artist Sonia Levy made a film about Project Coral as part of a residency with the arts organisation Obsidian Coast. *For the Love of Corals* (2018) documents the coral aquariums in the back of house laboratories of the Horniman Museum (Figure 3). The film shows the scientists at work and captures footage of the corals at various stages of development, rendering the developing embryos visible to the human eye through the inclusion of magnified footage, which is both beautiful and otherworldly, prompting both wonder and affection towards these lifeforms. The accompanying soundtrack was developed from recordings taken on-site at the Horniman and includes the sound of a coral skeleton disintegrating in reference to the fatal bleaching events threatening coral reef ecosystems ('About the Art: Sonia Levy', 2018).

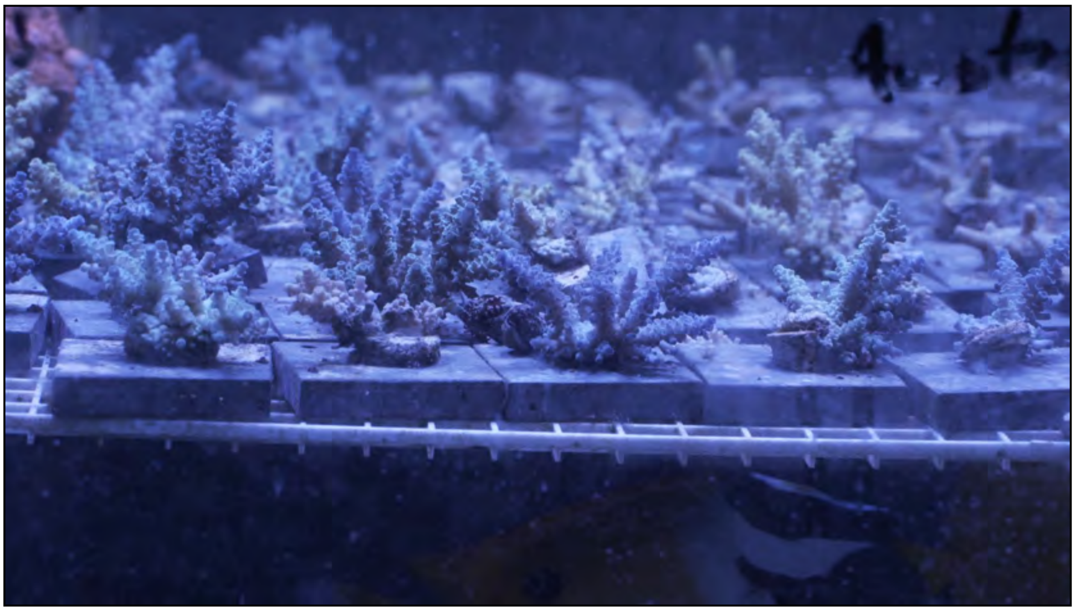

Figure 3. Sonia Levy, For the Love of Corals *(film still) (2018). Lab-grown corals from the genus Acropora, born and bred at the Horniman.*

Levy shows corals to be surreal and marvelous in footage that recalls the balletic underwater scenes of sea creatures in the films of Jean Painlevé and Geneviève Hamon, which were similarly filmed through the glass walls of aquaria. While Painlevé and Hamon's films are known for combining the alien and the anthropomorphic, Levy languishes in coral's far from human qualities alone. Coral and other lifeforms that inhabit the sea can present challenges for wildlife conservation campaigns because they are out of sight, hard to comprehend and are often perceived to lack the 'cuddly' charisma that more typically induces a desire to care. Yet as the art historian Marion Endt-Jones has observed, coral has recently proliferated in exhibitions as a 'harbinger of climate change' (Endt-Jones, 2020: 183). Levy's film starkly visualises the damaged ecologies of the Anthropocene, which are made tangible through the entanglements of humans and corals fundamental to the delivery of Project Coral. Yet, the project has an optimistic spin. Levy's website states that Project Coral represents 'a case study of new paradigms for multispecies living, environmental conservation and natural history that are emerging in the wake of the Anthropocene' (sonialevy.net). Indeed, in *For the Love of Corals* scientists are shown intervening in the reproductive lives of these captive corals in a dimly lit basement laboratory to repair the effects of anthropogenic activities that render these creatures and their habitats vulnerable in the wild. The scientists are captured expressing curiosity towards corals, manifesting their care and concern for these species and reef habitats in ecologically troubled times through their delicate and methodical work. Despite uncertain ecological futures, in pursuit of their research these scientists manifest their hope, performing what the anthropologist Anna Lowenhaupt Tsing (2015) has called *living in the ruins*, where possibilities for flourishing might emerge from crisis when practices of care and responsibility are cultivated. Such concerns are at the heart of Levy's film. Not only this, but the captivating footage of vulnerable, developing coral embryos can raise awareness about these creatures' plight and also induce a desire to care as their lives slowly and seductively take shape before viewers' eyes.

Levy's project was not commissioned by the Horniman Museum and Gardens and was not developed to be specifically displayed in the museum itself. It has been presented in various contexts outside the museum and also has an online presence through an iteration of the project subtitled *An Ecology of Perhaps* on the Critical Zones website (https://critical-zones.zkm.de/#!/detail:for-the-love-of-corals). Viewers are likely to be principally from a predominantly art-focused audience, presenting possibilities for taking Project Coral beyond the museum's walls to engage individuals who may not ordinarily visit a natural history museum with the concerns at the centre of this project. This work underlines that as much as contemporary art can provide new ways into thinking through and engaging with ecological issues in natural history collections, natural history collections also provide the material, impetus or catalyst for artists to develop work on these topics, making the ongoing dialogue across these disciplines central to the development of this work. The result for museums is the genuine possibility of offering new forms of encounter to visitors of arts and science institutions alike.

Conclusion

Natural history collections have been taking various approaches to exhibiting environmental crisis with the commissioning and display of contemporary art being just one of the many methods at work. The case studies discussed have been shown to present opportunities for raising awareness about ecological issues and engaging visitors in multisensory and emotive ways, providing another route into the issues at stake in this work. These projects have all fostered an interdisciplinary approach, bringing art and the natural sciences into relation with one another in ecological ways to create experimental and generative methods with which to think through environmental issues and provide space to imagine and enact more positive ecological futures.

Collaboration has been an essential part of these programmes and their long-term durations allowed time and space for trust and relationships to develop between participants as they gained insight into the different ways each other work, as well as for audiences to become accustomed to encountering these projects in the museum space. Developing new programmes for existing and new audiences sits at the riskier end of audience development activities for institutions and is something that needs dedicated time and resources to deliver (Audience Agency 2020). This was clearly recognised through the projects discussed, two of which had dedicated funding to develop this stream of work and all of which committed to this activity on a long-term basis. In each instance, bringing art and natural history museum professionals together to deliver the projects was central to successful delivery. *The Ship: The Art of Climate Change* was an exhibition resulting from a partnership between an arts organisation and a natural history museum at a time when the museum had just appointed its first dedicated curator of contemporary art. The Museum für Naturkunde, Berlin, appointed art curators on a freelance basis to work alongside museum colleagues to facilitate the delivery of a series of interventions. Finally, the Horniman Museum and Gardens has hosted touring exhibitions (*MELTDOWN: Visualising Climate Change)* as well as exhibitions resulting from residencies supported by arts organisations and facilitated dialogue between museum professionals and the artists themselves. It becomes clear then, to extend the analogy, that as well as ecologies of display, this field of practice results in ecologies of researchers and practitioners, where the interrelationships between a variety of professionals, their specific expertise and interests and the ways they respond to the museum environment from different disciplinary perspectives becomes crucial to this lively field of exhibition-making. Not only do such projects present possibilities for novel outcomes by bringing diverse perspectives and ways of working together, but through their collaborative and interdisciplinary character they provide a blueprint for the sort of collective and multidisciplinary approach that urgent global issues such as environmental breakdown demand.

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Creative Collaborations: Humanities programming in a natural history museum

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Abstract

Many museums seek new opportunities to creatively collaborate while sharing their story. The Werner Wildlife Museum at Casper College, located in central Wyoming, has actively engaged in creative initiatives that focus on humanities programming with primary, secondary, and higher education students majoring in diverse disciplines. Once seen as a museum "full of dead things" the museum is working to encourage a new perception as a place for active learning through humanities programming, as detailed in this article.

Keywords: Natural history, humanities programming, wildlife museum, collaboration, museum studies, arts

Introduction

The Werner Wildlife Museum at Casper College has been undertaking initiatives, such as humanities programming, to connect more students with its natural history collections. Located in the central United States, in Wyoming, the Werner is one of two institutional museums. The Werner Wildlife Museum and it's collections were gifted to the College 50 years ago by rancher Herman Werner (1892-1973), who collected specimens in diverse geographical locations from Australia to India and the Rocky Mountain west, which surrounds Casper College. As a recreational hunter, Werner collected specimens throughout his life joining safaris in Tanganyika (The United Republic of Tanzania) and chartering a ship, with crew, to reach Polar Bear off Spitsbergen Island (Norway). These specimens were considered trophies. The 11' foot tall polar bear (*Ursus maritimus,* Phipps 1774) was ranked 30th in the Boone and Crockett records of big game animals when donated in 1973 with several other polar bear specimens (Howard, 1973, p. 4). Mr. Werner spoke of his hunt in Alaska noting, "If anyone is interested in fresh air and a thrill, he should take on a polar bear" (*Casper Star-Tribune*, 1965, p. 7). These trophies weighed between 800-1,400 pounds and today, dazzle the eyes of many visitors, especially young children.

Early plans for the museum proposed exhibiting Wyoming wildlife with commissioned landscape murals highlighting "life zones" from mountains to prairies and the icy northern home of these bears (*Casper Star-Tribune*, 1970, p. 24). His idea for a museum was a response to "requests of some of the city's schools and other groups to see his wildlife trophies, which first prompted him to think of a permanent repository for the trophies and other outstanding trophies that would be of interest in the community" *(Casper Star-Tribune*, 1965, p. 7). The City of Casper donated the land and Mr. Werner financially supported the construction effort of a 5,000 square foot building (Figure 1). The idea of sharing the natural history collections space with art was one of Werner's initial ideas and the museum housed exhibitions of art by members of the Casper Artists' Guild in early years. That practice was later discontinued but has been revisited today to engage student visitors in connecting with the specimens. In 1965 Werner stated, "I sincerely hope that this museum will be a point of interest and attraction. It will be educational. I hope to have literature, books and pictures and so forth, that people can read and acquaint themselves more with wildlife and what wildlife means to young people growing up today" (*Casper Star-Tribune*, 1965, p. 7). Humanities programming at the Werner Wildlife Museum allows this connection, that Werner foresaw, between primary, secondary, and college students seeking emic understanding of their world.

Museum collections and staffing resources

The museum collections were initially assembled from multiple sources inclusive of Herman Werner's trophies, the Ullery Collection, the Utzinger collection of 15 Rocky Mountain Bighorn Sheep from the city of Casper, the U.S. Fish and Wildlife Service, avian taxidermist Nate Gibson, and donations from Casper College faculty. In the spring of 1977, the Werner Wildlife Museum lower level was expanded with a diorama containing North American pronghorn antelope and a badger in a prairie life zone (*Casper Star-Tribune*, 1977). Alumni contributed as well; a former Casper College Zoology student donated a platypus (*Ornithorhynchus anatinus*, Shaw 1799) and other examples of Australian mammals (*Casper Star-Tribune*, 1980).

Today, the museum houses just over 400 taxidermied wildlife specimens, 90 percent of which are on exhibit. The large majority of them are from North America. While much of the collection was initially donated 50 years ago, there have been many additional acquisitions including an albino mule deer (*Odocoileus hemionus*, Rafinesque 1817), an endangered Black-footed ferret (*Mustela nigripes*, Audubon & Bachman 1851) and most recently, a North American sheep "grand slam" (Dall Sheep, *Ovis dalli* Nelson 1884); (Rocky Mountain Bighorn Sheep, *Ovis canadensis* Shaw 1804); (Stone Sheep, *Ovis dalli stonei* J. A. Allen 1897); (Desert Bighorn Sheep, *Ovis canadensis nelsoni* Merriam 1897).

The museum has three staff members, two of which are part time and an advisory board. Part-time staff members perform visitor services functions as the "face" of the museum, providing tours for primary school groups, drafting the museum newsletter and developing programs such as the lecture series and the summer programming.

Figure 1. Werner Wildlife Museum 2015. (Photo India Hayford)

Additional responsibilities include collections concerns such as cleaning the mounts and maintaining the database. The museum director, whose office is located in the Tate Geological Museum at Casper College, develops new programming, liaises with college faculty, and is concerned with budgetary and institutional matters. As with most museums, staff are "wearing many hats" and thus, bigger programming ideas face limitations. However, partnering with college faculty in areas outside the School of Science has opened the door to understanding the collections in new manners. Beyond the scientific didactic knowledge provided in the exhibitions, humanities faculty are posing questions about the collection itself. How and why were the specimens collected? By whom? What is the human connection? What is our emic reaction to inquiry and observation of the natural world? Probing epistemological context can help students engage with collections.

Learning through museum collections

Through the centuries, scientific collections at institutions of higher learning have inspired students. For example, Rembrandt van Rijn as a young student at Leiden University would have experienced the Hortus botanicus where the tulip was first cultivated; tulips are realistically painted in the oil painting *Saskia as Flora* (van Putten and Schaeps, 2019). The Hortus botanicus also held cabinets of curiosities inclusive of animals, skeletons, and natural specimens. Perhaps this inspired the room of objects including biological collections of shells and that Rembrandt kept in his Amsterdam home when a working artist. In the 19th century, the Paris Botanic Garden collection offered reference for the exotic landscape backgrounds in works by Henri Rousseau as he learned to paint.

Centuries later, learning through collections continues; museum educators and teachers study and use myriad theoretical frameworks to facilitate significant understanding of the natural world (Black, 2007; Hohenstein and Moussouri, 2017; Genoways, ed., 2006; Hilton, Watkins-Colwell, and Huber, 2021; McCarthy, 2020). Museum educators can also find publications for training their staff and docents (Johnson, *et. al*, 2009; Talboys 2005). Museum conferences and organizations are instrumental in the exchange of ideas for teaching through collections. An example is the Natural History Education DemoCamp (2020) through The Society for the Preservation of Natural History Collections, aimed at sharing methods for museum educators to facilitate more learning opportunities utilizing their museum's collections. Other examples of science programming based on museum collections, developed by museum educators, can also be found online including resources through museums such as the American Museum of Natural History in New York (American Museum of Natural History, 2021).

At the Werner Wildlife Museum, programs to engage the community, developed by staff with a biology background, included a monthly lecture series highlighting the work of both professional and community scientists as well as a children's education program that was held in the backyard during the summer months. The Werner Wildlife Museum has also traditionally worked with teachers, especially from Casper College. In past decades, the museum hosted a curator from the Biology department and worked with Casper College science classes to host Wildlife Management and Environmental Science classes.

The intersection of art and science can also be found in some museum programs today. An example of community adult education at Harvard Museum of Natural History that involves the arts is *Sketching and Mindfulness*, "for deepening mindful awareness of our surroundings, and how mindful awareness can enrich... sketching practice" (Harvard Museum of Natural History, 2021). Other museums include art such as the *Birds of America* collection by John James Audubon at the Natural History Museum in London, which can help visitors frame their understanding of birds in natural settings through a different modality than a diorama or exhibition case. An example at the Wales National Museum was an installation titled NOMORPLASTIC sea plastic displays, which allowed "working with young people to make space for activism in the museum" (National Museum of Wales, 2021). This was considered an artistic response to the problem, engaging students to look closer at their world. The natural world is vast and enticing. Nature surrounds and engulfs us, even in urban settings, but few people really take the time and effort to study the natural world around them. Natural history museums can bridge that gap and the Werner Wildlife Museum staff wanted to expand beyond their traditional audience and engage students through humanities disciplines such as the visual arts, English and communication, and museum studies.

A shift to learning in the humanities with museum collections

In an effort to reach new audiences and expand the museum's engagement with students, an in-depth review of the history of the collection at the Werner Wildlife Museum was begun but there was the problematic issue of limited didactic information on the specimens, which would limit some academic probes of the collection. Taking another road to engagement, exploring an individual's response to the collections, yielded a different avenue of inquiry and learning - through the humanities. Stakeholders considered the work of theorists, such as Falk (2013) on how visitors make meaning, and Roppola's (2012) concept of "broadening". After also extensively studying visitor experiences, Roppola (2012) found four processes including framing, resonating, channeling and broadening as ways that people interface with exhibitions. Broadening is "context-related meaning" made by visitors "across multiple planes"; visitors become "co-participants in the creation of discourses" (Roppola, 2012, p. 216; 256). As Roppola (2012) stated, "Taxidermied specimens can be decontextualized from the natural world" and to alleviate this phenomenon, necessitates "an interrelationship within a broader scheme, within a story" (p. 228). The object experience and the affective manner in which the object can be understood is part of this theory. The humanities programs used at the Werner Wildlife Museum, discussed below, offer concrete ways to embed the specimen in our respective stories. College students, as an audience that is striving to learn, tell their stories, and consistently trying to "connect", are ideally suited to this pedagogy.

This type of expanded use of collections has also been recently developed at the University of Wyoming Art Museum. The Pat Guthrie Special Exhibition Teaching Gallery project involves object based learning for college students from various University of Wyoming majors. Faculty select works of art from the museum collection that relate to their specific course outcomes. In the fall of 2021, this included courses in environmental studies, chemistry, history, anthropology, and geology (University of Wyoming Art Museum, 2021). Students at Brown University even reimagined the "lost" natural history collection of the Jenks Museum through the lens of art and history, as a catalyst for understanding the history of museums and visitor engagement (Lubar, 2017).

Researching collaborations

To glean how other colleges were using the collection for object-based learning, and to investigate humanities programming at other institutions, Museum Director, Patti Wood Finkle, and Museum Studies Professor Valerie Innella Maiers reached out to the education staff at the Victoria & Albert Museum (V&A) seeking to better understand, not only the practical applications of such a program, but also to gain an understanding of their development and creation. Colleagues at the V&A offered guidance and advice, which were instrumental in the conceptual development and inclusion of this concept into the current Museum Studies curriculum. The backpack program at the V&A allows families to engage with new and permanent exhibits without the need for an age-appropriate tour or tour guide. They come with trails and activities for a specific age range and are free for visitors to check out using an ID for collateral. Habitat/travel bags, as exemplified by the V&A, were discussed. These types of backpacks encourage families to think about different locations and have items to help "transport them" to another location. There was a brief brainstorming session on creating a South American travel bag in conjunction with the quetzal specimen that could include a rainstick to mimic the sounds of rain, maps to discuss travel routes, and hats and gloves appropriate to the environment. These props could assist a variety of learners (audio, tactile, even aroma, in theory) and a variety of ages to engage with the exhibits in a new way. It was proposed that younger learners may enjoy the dress up aspect, while older siblings might enjoy plotting a route on the map. It was also revealed that while ages 6-7 make the most use of the backpacks at the V&A, it seems that they helped the families of the under 5 age group stay focused longer than those of the same age who didn't use a backpack. Other relevant topics covered appropriate age ranges for backpacks, developing activities, and looking for low-cost items that were both easy to clean and durable.

Based on this research coming back to Casper College, museum studies students developed a lesson plan to create parameters for visitor usage and an activity to engage and educate museum guests about museum specimens. These practical exercises for future museum professionals create opportunities for learning about natural history collections in tandem with cultural history and practice.

Using these interactions, Casper College museum studies students were prompted to create lesson plans for "education backpacks" focusing on specimens, such as the resplendent Quetzal (Figure 2), which stands out from many other collection specimens, having been collected 100 years ago. Praxis was connected with theory, such as Howard Gardner's (1985) theory of multiple intelligences, in designing the resources, to increase accessibility for users of the backpacks. Increasing accessibility, cultivating understanding of the natural world, and seeking to understand how

Figure 2. Quetzal, Pharomachrus mocinno, WM00285, La Llave 1832.

the collections were established, with all of the inherent problems of that process, are concerns for the Werner Wildlife Museum.

Humanities and creative collaborations at the Werner Wildlife Museum

The Werner Wildlife Museum has now been exploring new avenues to diversify how the collections are utilized, especially by the modern college student, beyond the traditional science programming.

Visual arts

New collaborations include co-hosting various events with the Visual Arts department to bring students to the museum, for the first time, as well as working with instructors' pedagogy. For exercises in learning about creating forms in three-dimensional space, art students in a sculpture class created wire "sketches" of the specimens in the museum galleries. In a drawing seminar, students brought their drawing pads and explored specimen grouping. In another example, ceramics classes visited the museum and gained inspiration from the exhibits. Working both in the museum to sketch or photograph their specimen, they returned to the studio to begin creating their piece. Students revisit the museum on multiple occasions to view the specimen or to ask the staff questions. This has yielded both exhibitions of the ceramic art in the museum and in other locations with a natural setting such as along the Platte River Trail in Casper. (Figure 3)This art collaboration, initially only open to students, has grown into two professional juried art shows facilitated by the museum each academic year. The museum issues a statewide call for artists with a wildlife or nature theme inclusive of fine art in the fall, and craft pieces such as needlework and leather working in the spring. The staff have worked to

Figure 3. Ceramic art installed at the Werner Wildlife Museum. (Photo Patti Wood Finkle)

Figure 4. Poetry, Pottery, and Paintings *Poster, Casper College.*

cultivate relationships with local artists, particularly art students, and also with others from around the state in order to bring more artistic diversity to the show (Figure 4. *Poetry, Pottery, and Paintings Poster*, Casper College).

English and communication

Another creative collaboration was established with the Casper College Department of English. through a collaborative process, faculty provided workshops for students and the community in a program titled, the *Werner Wildlife Museum's Writers Workshop*. The idea originated with a program given by the American Museum of Western Art (2018), who invited a writer's group to their facility to be inspired by the art. The Werner Wildlife Museum's director realized the potential for a similar program and partnered with the Casper College English department for a new winter program that highlighted the museum's collections as well as invited a new and unique (to Casper College) opportunity for students to engage with each other outside of the classroom. Faculty facilitated the workshops , choosing topics that interested and inspired them, increasing their engagement with the participants in the evening programs.

In one workshop, the faculty member taught "reductive writing" by taking pieces of literature, magazine articles, pages from books, and other media and subtracting the language that wasn't deemed necessary by the workshop participant. Pages were appropriated and re-imagined leaving an entirely new piece, built upon an original work. Another faculty member, who is a published wildlife writer, talked about the genera and gave both critiques on pieces produced in his workshop as well as advice on submitting articles to wildlife magazines. After each semester, the Museum published these creative endeavors in a booklet that was produced with the Casper College Public Relations department. (Figure 5) For several Casper College students aspiring to be writers, this was their first publication.

Museum studies

Casper College Museum Studies students also worked with the Werner Wildlife Museum to learn about curating an art exhibition; including the issues of creating knowledge, appropriating culture and/or identity, and manners of exposing

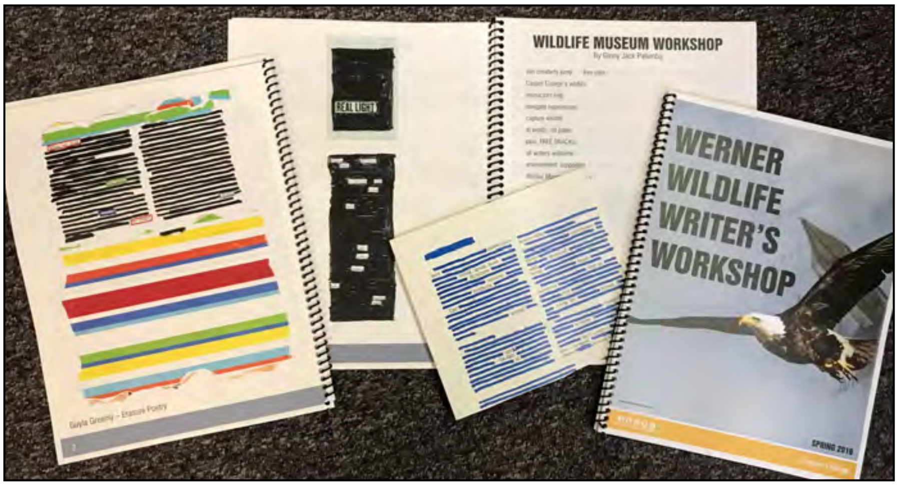

Figure 5. Werner Wildlife Writer's Workshop publication and example pieces. (Photo Patti Wood Finkle)

personal worldviews when drafting signage. When writing catalog entries for each artwork, along with researched biographies of the painters, students asked themselves: "How does the artist's conceptualization of the composition relate to the artist's connection with nature?" and "What might resonate with the viewers in their understanding of that environment?". Revealing and explaining their personal understanding was important to the narrative. For the opening of the exhibition, students invited faculty and students from other academic departments to offer activities from star observations to poetry reading. Additionally, a secondary school teacher planned an education activity that linked natural science and art further strengthening the humanities collaborations seen throughout the program.

Primary and secondary education

As these creative collaborations have grown, more primary and secondary teachers have started using the Werner Wildlife Museum for humanities programs. Another program, that was developed by a local kindergarten/first grade (5-7 year olds) school teacher with museum staff, is the "Wildlife Presentations with Woods Learning Center" night. The primary school teacher wanted to encourage her students' writing and oral speaking skills in conjunction with first grade curriculum outcomes, with a topic that would interest the entire class. She reached out the staff at the Werner to see if there were learning opportunities beyond the traditional museum tour and together they developed a plan to have the students visit the museum, identify and research a specific attribute of an animal (habitat, diet, appearance, adaptations, etc.), write a one paragraph report, and present their findings to friends and family at an evening open house event. These students learn new vocabulary, to write in complete sentences, how to face their audience when presenting, and the importance of encouraging each other. The museum facilitates the research and the open house, providing punch and cookies. In return, the Werner has more than 200 visitors for each open house, and sees dozens of new people each year, many of them families of the young scholars who love to tell staff about "their " animals and recount all that they learned. At a local secondary school, fine arts faculty have brought their classes weekly to sharpen drawing skills using the displayed specimens as models.

Future creative collaborations

Future initiatives for the Werner Wildlife Museum include ideas that will allow the collection to grow as well as provide immersive visitor interactions.

Environmental Science

Currently, the staff and board are exploring the creation and maintenance of a wild space near the museum that would feature native plants to attract local fauna. While this idea is not unique to the Werner, certainly it has been championed by larger institutions for years, it is an idea that has not been explored in Wyoming where wildlife seamlessly converges on campus, from wild turkeys, antelope, and deer to fox and ground squirrels. The idea was born out of the desire to teach people the difference between native and non-native plants in the area and to attract local wildlife for viewing. The closest similar space is located in Cheyenne, Wyoming just over two and a half hours away, by car. The space is a free-standing Children's Garden in a city park that incorporates both native and non-native plants into an interactive space, but it is only accessible during certain hours and is not accessible to wildlife, with the exception of birds and a few squirrels. The Werner space will be accessible 24 hours a day, rain or shine, to people and wildlife. It will provide a space for visitors to walk, and can be utilized as an outdoor classroom space for primary, secondary, and higher education classes. Creating this new "gallery", a tactile space full of scent and textures, allows for the touch of non-toxic native grasses and plants, thereby meeting the needs of differently abled visitors. The project should spark further programming both with the museum and the natural space, especially for courses in the School of Science and the School of Fine Arts and Humanities that have an environmental scope, such as the Environmental Literature course.

Travel and tourism

A future program for students of higher education in the Casper College Outdoor Tourism and Recreation major in the School of Business and Industry could consider eco-tourism and the toll on some sites but economic benefits to communities. Thus, opportunities to connect to the natural world, collaborate creatively, and learn abound.

Conclusion

The Werner Wildlife Museum at Casper College aspires to create new and innovative learning opportunities. Through thoughtful collaborations, such as faculty directed and facilitated programming within the humanities, the museum has expanded its offerings, created new partnerships, and brought the natural world to a new generation of visitors.

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Recording of Blaschka glass invertebrate models: A method and workflow for imaging using standardized methods

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Abstract

The glass models of marine invertebrates, made by Leopold and Rudolph Blaschka from 1863 to 1890, encompass more than 700 species and hold significant historic, scientific, and artistic value. Each model is unique, varying in size, colour, and complexity. Two models of the same species may show variation in design and even construction. This diversity of design spans nearly three decades of production, creating an issue with consistency when comparing models and sharing information about Blaschka collections. As important heritage objects, the models need to be researched, understood, maintained, conserved, and publicly exhibited. For this to occur, it is important to be able to compare and reference models, both within a specific collection and across collections worldwide. The most effective way to achieve this is through standardized imaging and digitization. Currently, there is no standard photographic method used to digitally reproduce and record the diversity of Blaschka models, and no resource-efficient approach proposed for imaging the damage and deterioration affecting the models. Here we present an efficient workflow for accurately recording all types of models, tested on the Blaschka collection housed at the National Museum Ireland – Natural History. We establish a standardized photographic method to digitally record the true size, colour, and design of each model and present easy and affordable techniques to record their material composition, existing damage, and structural integrity. The final images are accurate digital surrogates of the original objects, which can be associated with metadata, used, and shared. This workflow was designed to be scalable and applicable to any Blaschka collection, to ensure the digital preservation of each model. This can help researchers, conservators, and curators make better-informed identifications, comparisons, and decisions for safe storage, display, and conservation practice, while providing materials for museum education, outreach, and marketing.

Keywords: Leopold Blaschka, Rudolf Blaschka, conservation, glass model, invertebrate, photography, museum photography

Introduction

The Blaschka workshop in Dresden, established in 1863 by Leopold Blaschka (b. 27 May 1822 – d. 3 July 1895), produced thousands of invertebrate glass models until 1890. These models were sold worldwide through a network of dealers (Reiling & Spunarová, 2005) using catalogues in German (DE) and English (ENG) [1863 (DE), 1867 (DE), 1871 (DE), 1878 (ENG), 1885 (DE) and 1888 (ENG)].

The catalogues never contained any pictures, and the models were not consistently numbered until 1878 in the first catalogue edited in English by Henry Augustus Ward (b. March 9 1834 – d. July 4 1906), one of the main dealers in the USA. Moreover, each model could sometimes include several sub-elements (e.g., developmental stages). From 1863 onward, models evolved in design over three decades of production, making comparison, evaluation, and documentation of models held in museums a complex undertaking, especially when comparing early specimens to later examples.

The most effective way to compare models is to place them side by side, but this usually requires extended handling and transport, which poses a significant risk to the fragile models. The next best approach is to use standardized digital imaging, but most photography treats the Blaschka models as works of art and so aesthetics dominate. This often means that scale is not included, there is no colour accuracy or supporting colour calibration employed, damaged areas are avoided (or even digitally 'repaired'), and perspective shots dominate rather than standard, comparable reference shots (i.e., lateral, superior, inferior, anterior, and posterior views from the sagittal, coronal, and transverse planes). There are many images of Blaschka models accessible on online public databases managed by a variety of institutions (e.g., Tyne & Wear Archives and Museums (https://collectionssearchtwmuseums.org.uk/), National Museums Scotland (https://www.nms.ac.uk/explore-our-collections/search-our-collections/), Cornell University (https://digital.library.cornell.edu/)); however, each institution's photographs vary in usage of background colour, scale bar, colour reference card, and the perspective from which the model was photographed. Other groups have been using photogrammetry or 3D scanning (Abate *et al*., 2017, Fried *et al*., 2020) and online repositories such as Sketchfab (https://sketchfab.com/ARC-3D/collections/the-blaschka-marine-invertebrates), but those technologies do not allow for the recording of large numbers of models from various locations, as equipment and training in the methods is not yet widespread. The technologies do provide pleasing digital 3D models, but they can be difficult to use for curation or comparative assessment. The use of 360° low speed videos of models has also been presented on websites, but lighting, shadowing, and lack of references affect their use.

In this era of data, where we are more equipped to share and aggregate information, there is a clear and recognized need to establish reference protocols that allow the standardized recording of Blaschka collections. This applies as much to images as data, to allow sharing between colleagues, researchers, and museums to enable analysis, comparison, and assessment. Today, high quality digitization requires large teams, expert-level experience, expensive equipment and software, time, and space. Most museums do not have the resources to achieve this. For a standardized imaging protocol to be successfully universal and applicable to all collections, a resource efficient approach capable of producing high quality, accurate, digital surrogates of each model is required.

To address this need for Blaschka collections, we took advantage of the high concentration of models on the island of Ireland. 952 invertebrate models have been recorded in six separate Irish collections (National Museum of Ireland – Natural History, Trinity College Dublin, University College Dublin, National University of Ireland Galway, University College Cork, Queen's University Belfast), meaning Ireland has one of the largest collections of invertebrate models in the world (Doyle *et al*., 2016). We worked specifically with the collection of approximately 580 models at the National Museum of Ireland – Natural History (NMINH) to develop and test a protocol.

Here, we present an easy, affordable, and scalable approach to accurately digitize all Blaschka collections. We explain an efficient workflow to record all types of models and establish a standardized imaging protocol to produce accurate, digital surrogates of each model. Our method enables the accurate capture of each specimen's colour and correct dimensions; employs a uniform composition protocol for reliable, taxonomic reference; and describes a simple photographic approach utilizing high intensity light and inverted image procession to record and help assess the damage, material composition, and structural integrity of each model without the need for expensive equipment. To facilitate digital archiving and distribution, we put forth a post-processing protocol to ensure the final images of each model are visually and digitally uniform. Lastly, we set a range of standardized options for implementing our precise workflow to augment successful implementation across all collections.

Materials and methods

Photography equipment and software

Quality object photography requires a camera proven to work for product photography, but final camera choice will depend on photographers' ability level and preferences. Some of the best cameras for product photography include: Sony Cyber-Shot DSC-RX10 II; Sony A6100; Fujifilm X-S10; Sony RX100 V; Olympus OM-D E-M10 Mark IV; Nikon D3500; Canon Rebel SL3; Canon EOS M50 Mark II; Sony A7R IV; Canon PowerShot G1 X Mark III.

The equipment used in this photographic standardization of the models included a Sony Cyber-Shot DSC-RX10 II digital camera with attached Carl Zeiss 24-200mm f/2.8 lens (35mm eq.); a studio tripod; 2x 7' light stands; 2x 10" diameter aluminium reflectors; 2x 135W 5500K CRI ≥ 95 Daylight Balanced CFL Photography Light Bulb; a 30" x 30" x 30" table; a 60" x 36" x 30" industrial work table; a 24" x 24" x 24" table top photo studio lighting soft box shooting tent with white and black backdrops; 2x clear 1/8" thick acrylic Plexiglas plastic risers (3" x 3"); 2x clear 1/8" thick acrylic Plexiglas plastic risers (6" x 6"); a 22" x 22" x ¼" clear acrylic Plexiglas plastic sheet; white and black card stock; an X-ACTO knife; 2x metric rulers; 6x 4.5" photography spring clamps; 2x plain matte tablecloths (white and black); 3x sandbags (5-10lb); 18% grey card; and an X-Rite ColourChecker Passport Photo 2 Target. The software used for editing the photographs included the X-Rite ColourChecker Passport Photo 2 Camera Calibration Software, Adobe Camera Raw, and Adobe Photoshop CC (see Appendix I).

Results

Photography workflow

Digital reproductions can be used to accurately identify, compare, and help assess the conditions of objects in museum collections (Merckx *et al*., 2018). A digital reproduction can also be used by scholars to study a museum object if it is an authentic, accurate, and high-quality digital surrogate of the physical original (Mudge *et al*., 2010). To achieve these standards for usability, a two-dimensional digital representation must measure as close as possible to 1:1 with the original three-dimensional object to be considered scientifically reliable (Geffert, 2011). While advanced three-dimensional digitization techniques offer an ideal standard for digitizing museum collections, using a simplified and standardized photography workflow can still create accurate and scientifically reliable digital reproductions at a fraction of the cost.

Set up

An office in the NMINH was converted into a photography studio suitable for shooting the models (Figure 1). The windows, doors, and light sources were blacked out in the space to control lighting and avoid ambient light. All extra museum objects, materials, lights, cables, and cords were removed so the equipment could be organized in the space. While the equipment and shooting materials were adjusted differently for each standardized image format, the arrangement seen in Figure 1 was established as the baseline studio setup.

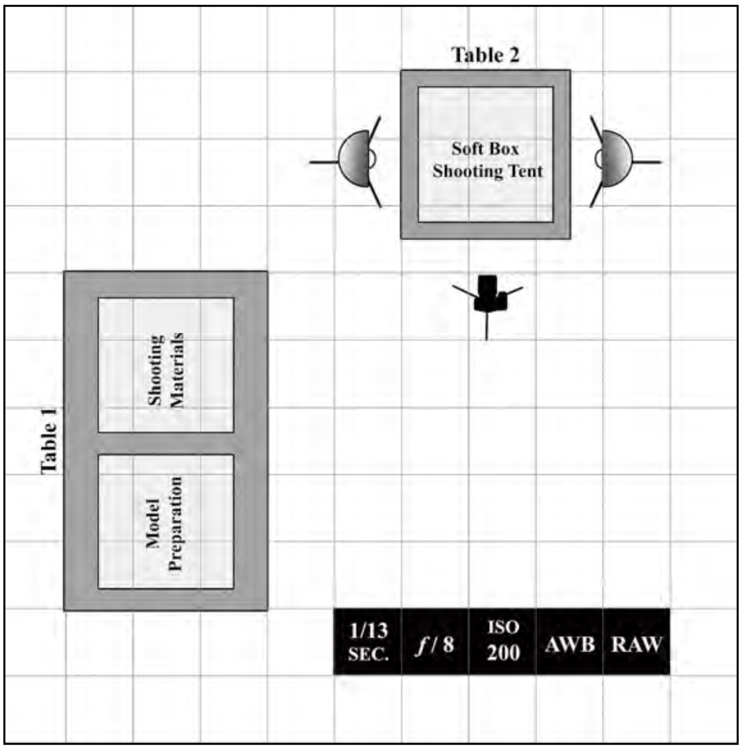

Figure 1. Baseline studio set up. Plan view.

Table 1 in Figure 1 was designated for preparation of the models and holding shooting materials needed for the standardized image formats. Table 2 in Figure 1 was used for the shooting setup. On Table 2, a soft box shooting tent was placed in the centre. This tent provided a broad, diffused light necessary to adequately illuminate a model without creating surface reflections. Capturing a model without reflections was critical, because reflections can alter or eliminate significant visual information on the surface of the model and reduce the accuracy of the digital capture. Two light stands were placed on either side of Table 2, their light bulbs aligned with the centre of the tent.

The camera was mounted on a tripod directly in front of Table 2 (Figure 1). Camera settings were adjusted based on the standardized image format being used and the model being photographed. The following exposure settings were utilized as a starting point: aperture f/8, shutter speed 1/13, ISO 200, white balance auto, and file type RAW. For all image formats, the 2-second delay self-timer was set to avoid image blur caused by camera shake.

Colour reference

For a digital reproduction of a Blaschka model to be honest and scientifically reliable, it must capture the model's true colour. Colour is a visual trait that helps characterize each model as an individual object in a collection. Colour also plays a significant role in the identification of a model's materials, the evaluation of those materials' level of stability, and the assessment of existing damage. However, achieving colour accuracy in a digital surrogate is challenging because captured colour data varies between devices (cameras, monitors, printers, etc.) (Sharma, 2018). Every device images colour differently and sets colour profiles automatically.

In general terms, a colour profile is a snapshot of colour at a specific moment on a specific device. More precisely, a colour profile is a data set assigned to specify the range of colour in a device and characterize a colour space (sRGB, AdobeRGB, ProPhotoRGB, etc.) (Fox *et al*., 2015). To achieve colour accuracy across devices, we needed to capture maximum colour data and establish colour profiles in a standardized, colour-managed workflow (Sharma, 2018).

To help establish a standardized colour workflow, we used RAW file format, a grey card, and the X-Rite ColourChecker Passport Photo 2 Target and camera calibration software for every image taken. Shooting in the RAW file ensured the capture of maximum colour data and enabled colour profiles to be assigned and embedded in an image file during post-processing (Fox *et al*., 2015). A grey card helped achieve proper exposure and set white balance, both of which can influence the appearance of colour in a digital reproduction (Berns, 2001). The X-Rite target and software were used to integrate consistent colour profiles into the workflow. The target was used when photographing the models, and the calibration program was applied during post-processing. We established a consistent method for using these tools in each of the standardized image formats (Figure 2).

For every image taken, we arranged the shooting setup and materials following the requirements of the standardized image format. The model being photographed was placed in the shooting setup and the lighting was adjusted. The model was carefully removed from the setup and the grey card was placed directly where the model was to be photographed to take a light meter reading to obtain proper exposure. After metering, the grey card was removed, and the model returned to its original placement. To create colour profiles, the target was placed next to the model and an initial image (snapshot) was taken. In the snapshot, the entire model and target were visible within the image frame, and the target positioned to reflect the light source. For organization purposes, the model's information card was also included in this snapshot. If anything changed in the shooting set up or workflow – including altering the lighting, paper, lightbox, drop sheets, etc. – the grey card was referenced again and an additional snapshot with the target was taken. After the snapshot was taken, the target and information card were removed, and the model was photographed on its own in the exact same setup. These steps were repeated for every image taken in the workflow.

During post-processing, the X-rite software was utilized to create colour profiles for each snapshot. Each snapshot was opened in Adobe Camera Raw, saved as a DNG file, and processed using the software to create its specific colour profile. This colour profile was saved into Adobe Camera Raw and Adobe Photoshop CC and used to achieve colour accuracy during post-processing.

Taxonomic reference

A uniform composition protocol, designating the number and type of views required to adequately capture each type of three-dimensional model, is necessary to establish consistency across digitized collections (Rivera, 2014). This consistency is critical in two-dimensional digitization for curators,

Figure 2. Caryophyllia smithii [123] NMINH:1886.243.1 photographed in standardized image format 6. ***(A)*** *Colour reference snapshot with the model, target, and the model's information card included in the image frame.* ***(B)*** *Photograph of the model on its own, in the same setup as the snapshot. Neither image has gone through post-processing.*

conservators, and researchers to recreate the physical research experience and accurately identify, investigate, and compare objects across and between collections (Bincsik *et al*., 2012). For our standardized composition protocol, depending on the taxonomic group and the keys necessary for its identification, the shooting setup was arranged so that each group of animals was effectively and uniformly represented along standard axes and views (Figure 3 and Table 2).

This specific composition protocol allowed for a better comparison of specimen as each image was calibrated in size. The standardized protocol followed the symmetrical body plan axes: anterior, posterior, ventral, dorsal and lateral views. Six standardized image formats were chosen to capture each model in its entirety for taxonomic comparison.

Damage reference

The existing physical damage on each model is a result of chance, transportation, handling, improper storage, and environmental factors (van Giffen *et al*., 2010). In some cases, fluctuations in temperature and relative humidity, as well as the existence of atmospheric pollutants, have exacerbated damage by causing deterioration to the models' compositional materials (Robinet, 2006). While the models are composed mostly of glass, other materials, such as metal wires, waxes, papers, glues, resins, and paints are also incorporated into their structures (van Giffen *et al*., 2015). Brass wire, cotton, wood, and plaster have been identified as additional integrated materials in models at the National Museum of Ireland – Natural History (Figure 4).

The models' main compositional material, glass, is susceptible to deterioration over time, because its surface absorbs moisture from the air. The interaction with atmospheric water triggers various corrosive processes, which can deteriorate the surface of the glass (Kunicki-Goldfinger, 2008).

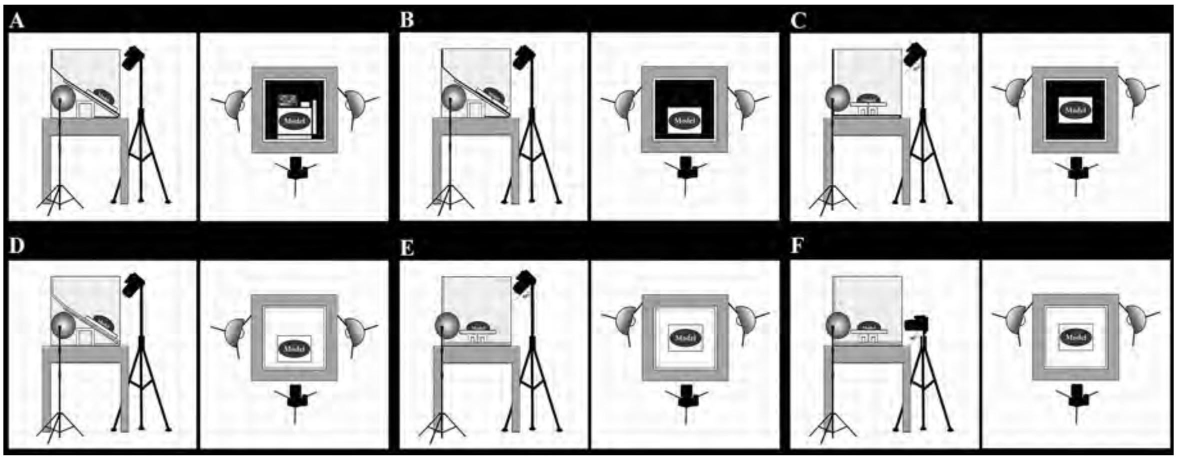

Figure 3. Standardized shooting setup for Taxonomic Reference image Formats 1-6. Side view and plan view shown for each format. ***(A)*** *Format 1: Reference Image* ***(B)*** *Format 2: Museum Plan View* ***(C)*** *Format 3: Museum 45°* ***(D)*** *Format 4: White Plan View* ***(E)*** *Format 5: White 45°****(F)*** *Format 6: White 90°.*

Table 2. Taxonomic Reference Standardize Image Formats 1-6. See ***Table S2 in Appendix I*** *for full shooting setup procedure.*

IMAGE FORMAT	DESCRIPTION
1: Reference Image	The model was photographed in dorsal view as it is displayed in the museum with its information card, the target, and rulers included for scale.
2: Museum Plan View	The model was photographed in dorsal view as it is displayed in the museum without the information card, target, or rulers in the frame.
3: Museum 45-degrees	The model was photographed at a 45-degree angle from its four main sides (front, back, right, and left lateral), as it is displayed in the museum. This image format was only used for models affixed to a flat base.
4: White Plan View	The model was photographed in dorsal view with any added base covered in white card stock.
5: White 45-degrees	The model was photographed at a 45-degree angle from its four main sides (front, back, right, and left lateral), with its base covered in white card stock.
6: White 90-degrees	The model was photographed at a 90-degree angle from its four main sides (front, back, right, and left lateral), with its base covered in white card stock.

This deterioration can lead to crizzling – the formation and spread of microcracks throughout the surface of the models' glass material. However, Blaschka models are not overly prone to crizzling and physical forces pose a far greater threat to the glass used in the models. Where large cracks and missing glass fragments from breakages expose internal metal materials, corrosion and deterioration accelerates in both the metal and glass (Szala *et al*., 2014). In models composed of multiple additional materials, deterioration is augmented further because each material has its own specific chemical and physical response to fluctuations in temperature and relative humidity. These varying responses stress the models internally, which can weaken, alter, and damage the material stability of their glass (van Giffen, 2019).

In some cases, this internal stress can increase the severity of pre-existing small cracks and cause the formation of new cracks. Eventually, accumulated cracks can cause the structural integrity of the model to fail. Detecting that damage can require the use of advanced and expensive equipment such as CT scanners or X-ray machines, which are not always accessible. However, for each individual model, photographing existing glass cracks can help to 1) identify, quantify, and record the model's physical damage and deterioration at a specific point in time; 2) help establish the model's material stability and structural integrity; and 3) inform decisions about storing, displaying, and caring for the specific model. Additionally, this digital record can allow it to serve as visual evidence of condition for conservation and evolution of the model condition over time.

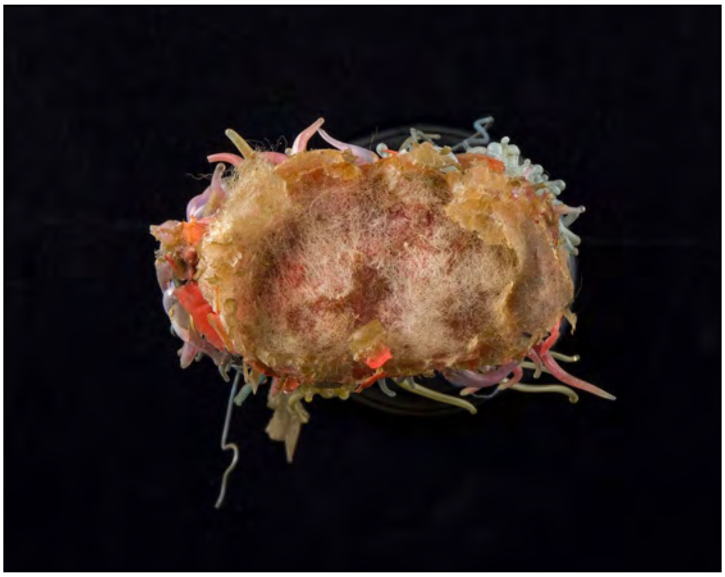

Figure 4. Detail of cotton fibres identified in Physalia caravella *[210] NMINH:2009.68.8.*

Table 3. Damage Reference Standardized Image Formats 7 and 8. See Table S3 in Appendix I for full shooting setup procedure.

Image Format	Description
7: Backlit 90-degrees	The model was photographed at a 90-degree angle from its four main sides (front, back, right, and left lateral), while backlit with high intensity light.
8: Underlit Plan View	The model was photographed in dorsal view, while underlit with high intensity light. This method was only used for models that were not attached to a base and could be moved without causing damage.

During the implementation of standardized image formats 4-6, photographs of existing cracks on a model's surface and form were recorded. For each model, every crack was photographed individually unless the crack extended through the model's entire surface or form. Varying from the standardized camera techniques of image formats 4 -6, for each individual crack recording, the camera was readjusted so the centre of the lens aligned with the centre of the crack. For cracks extending throughout the model's entirety, the lens was aligned with the centre of the model (Figure 6A).

Standardized image formats 7 and 8 were additionally created for our recording protocol to specifically highlight damages (Table 3). These simple approaches used high intensity light and inverted image post-processing to assess damages and augment the visibility of glass cracks and structural damage without the need for expensive equipment (Figure 5).

For both formats, the camera was set to black-and-white, and its contrast parameters were bumped up to +1 or +2 to maximize contrast and capture minute details (Coscia, 2012). The X-Rite target and software were not used for these formats, because the final edited images will be inverted, black-and-white images. However, the grey card was still used for exposure adjustments, and an initial snapshot with the model's information card was still taken for organization purposes. These two shooting setups tended to cause reflections on a model's surface from the photographer and equipment. To avoid this, the photographer dressed in all black, and the tripod, if reflective or brightly coloured, was covered with a black tablecloth.

Two additional viewpoints were photographed during standardized image format 8 to record each model's cracks, damage, and structural integrity, made more visible due to the underlighting Technique (Figure 6). First, photographs of each crack on a model's surface and form were recorded using the same method described in the standardized image formats 4-6. The utilization of high intensity light for underlighting, in conjunction with the inverted image post-processing method, illuminated the totality of cracks present. In some cases, these images also exposed unseen glass disease symptoms such as droplet formation, and hidden structural damage.

Second, the underside view of a model was recorded. This viewpoint was only photographed if a model was unattached to a base and could be moved, turned upside down, and placed on its dorsal surface (top side), without being damaged. Once safely inverted, the model was photographed again in the standardized image format 8. Viewing a model's underside can confirm cracks existing on

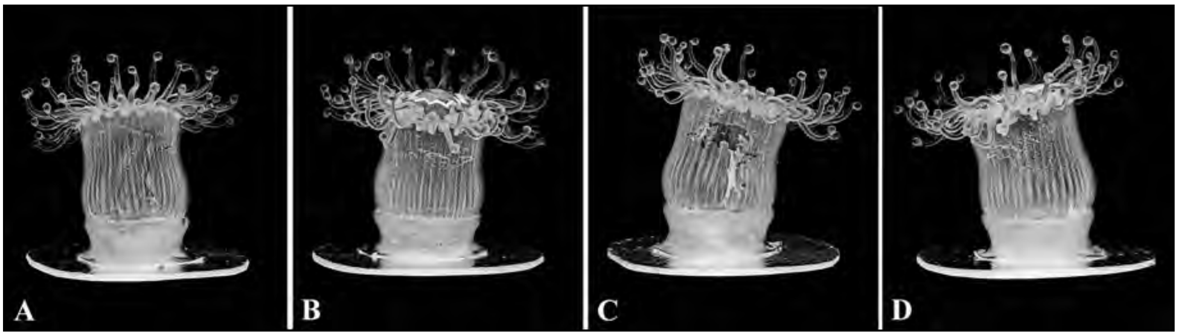

*Figure 5.*Caryophillia smithii *[122] NMINH:1886.243.1 photographed in standardized image format 7 to highlight cracks, and structural damage.*

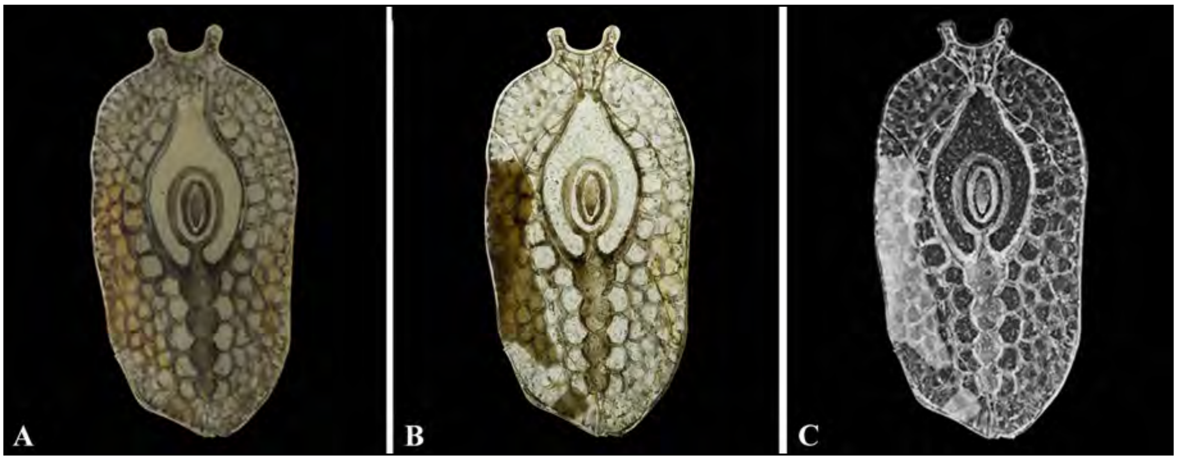

Figure 6. Stylostomum variabile *[666] NMINH:1878.186.1 photographed in formats 4 and 8. Cracks extend throughout entire object. (A) Model photographed in format 4. (B) Model photographed in Format 8 before post-processing. (C) Model photographed in format 8 after post-processing.*

its base and/or internal surfaces, cracks extending from its external surface through to its base and/or interior surfaces, and internal structural damage. This view can also reveal internal structural components, compositional methods, and materials normally hidden from view. Recording these elements, without damaging a model, can be critical to its conservation.

Image Processing and Post-processing for Communication and Conservation

Image File Formatting

The original RAW image files for all standardized image formats were never edited. All original RAW image files were appropriately named and saved in a folder, which was saved onto multiple storage devices for security. This folder was copied, duplicating each original RAW image file, and these files were used for post-processing. If a duplicated file was damaged at any point during editing, it was erased and replaced with another RAW image file duplicate. This step was crucial for preserving data captured by the camera on the original RAW image files. For each standardized image format, the final file (the accurate digital reproduction used for communication and conservation) was a high-resolution image saved as a TIFF file with 300 dpi and its largest pixel dimension using the accession number followed by a standardised description of the views separated with underscores e.g. 1886-751-1_BL90L (meaning specimen NMINH:1886.751.1, back-lit, 90°, lateral - see Appendix for full details).

Creating and Applying Colour Profiles

For every image type shot in the standardized image formats 1-6, the final file was created using two separate RAW image files. The first RAW image file (File 1) was the "snapshot" and included in the image frame the model set up in a standardized image format, its information card, and the X-rite target (Figure 7). The second RAW image file (File 2) included only the model set up in the same standardized image format, exactly as it was positioned in File 1. File 1 was needed to create an accurate colour profile that could be used to achieve colour accuracy when editing File 2.

To create a colour profile, File 1 was dragged into Adobe Photoshop CC, prompting the Adobe Camera Raw window to open. The "White Balance Tool" was selected from the Adobe Camera Raw dialog box, changing the cursor into a dropper. The dropper was used to click the white square on the imaged target, correcting the white balance. This image was saved as a DNG image file (Digital Negative). The X-Rite software was opened, and the new DNG image file was dragged into the program window. The program's green grid system was manually aligned with the imaged target. Once aligned, the 'Create Profile' button was selected. An accurate colour profile was created by the program and was then saved to the 'Camera Profiles' folder. The file name was created using the standardized naming formats (see Appendix I). This colour profile could now be accessed through Adobe Camera Raw and Adobe Photoshop CC to achieve colour accuracy when editing File 2.

To apply the colour profile, File 2 was dragged into Adobe Photoshop CC, prompting the Adobe Camera Raw window to open. Clicking on the "Camera Calibration" icon, the recently saved

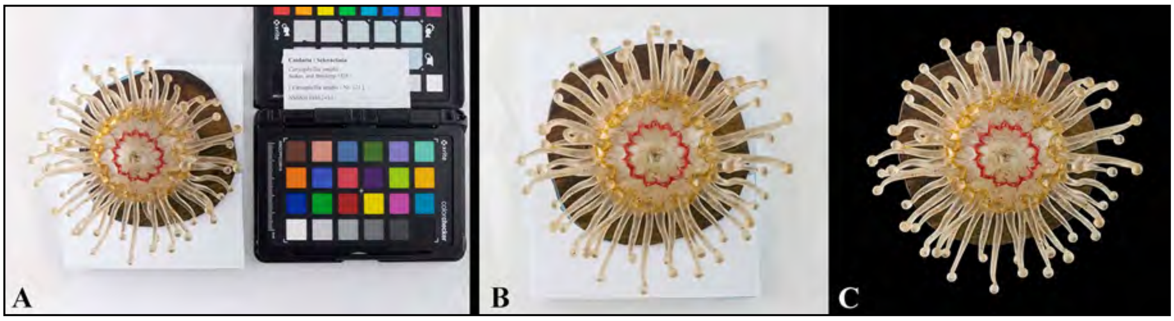

*Figure 7. Colour workflow images of NMINH:1886.243.1 photographed in format 4. **(A)** File 1(unedited). **(B)** File 2 (unedited). **(3)** File 2 with colour profile and all post-processing applied.*

colour profile was selected from the "Camera Profile" drop down tab. This selection applied the accurate colour profile to File 2, which could now be opened in Adobe Photoshop CC for editing. In the bottom right corner of the Adobe Camera Raw window, the "Open Image" button was selected, opening File 2 in Adobe Photoshop CC. Before any further edits, this Adobe Photoshop CC file was saved as a TIFF file. The file name was created using the standardized naming formats (see Appendix I). Note: to ensure accurate colour and proper visual editing, the display profile of the device used for editing was calibrated at the beginning of each post-processing session.

Applying Adjustment Layers to Images Captured in Formats 7-8

A colour profile was not created for photographs taken in the standardized image formats 7 and 8, because the final file for each image is an inverted, black-and-white image (Figure 8). Therefore, only one RAW image file was needed to create each image's final file. This RAW file included in the image frame just the model set up in a standardized image format. For each image, the RAW image file was dragged into Adobe Photoshop CC, prompting the Adobe Camera Raw window to open. White Balance was adjusted in this window. In the bottom right corner of the Adobe Camera Raw window, the "Open Image" button was selected, opening the file in Adobe Photoshop CC. Before any further edits, this Adobe Photoshop CC file was saved as a TIFF file. The file name was created using the standardized naming formats (see Appendix I).

While this image file was shot using the black-and-white camera setting, the RAW image file still included all colour data. To eliminate colour, the "Black and White Adjustment" layer was selected and applied. Next, the "Invert Adjustment" layer was selected and applied, inverting all pixel colours and brightness values in the image. This adjustment allowed dark areas of the image to become bright and bright areas to become dark. This also emphasized subtle details originally overpowered by colour, including cracks and internal structural materials. Once these details were identified, the "Brightness/Contrast Adjustment" layer was

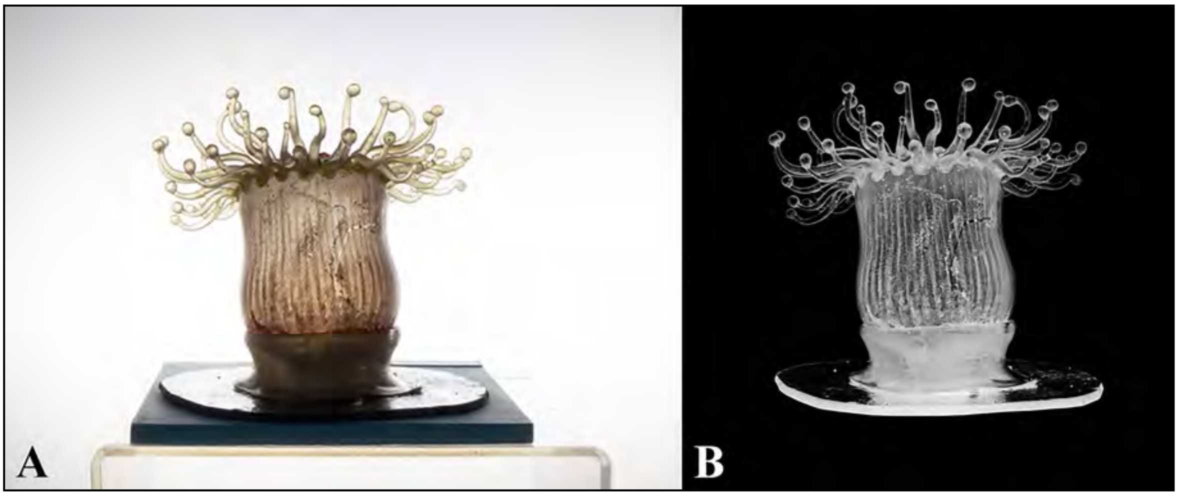

Figure 8. Caryoplillia smithii *[123] NMINH:1886.243.1 photographed in format 7. (A) Original RAW image file. **(B)** Original RAW image file with all adjustment layers applied.*

selected, toggled, and applied to further emphasize them. This was done carefully and sparingly so image data was not lost.

Removing Background Information

Adobe Photoshop CC was used to digitally remove unnecessary background information in each image file from all standardized image formats 1-8. This further increased utility and reduced variation of the digital image content, as well as simplified identification and comparison by isolating the model and its specific digital information.

To remove the background information in images shot in image formats 1-6, the TIFF image files (with their now accurate colour profiles) were used. For photographs taken in image formats 7 and 8, the TIFF image files (now inverted, black-and-white images) were used. These image files were opened in Adobe Photoshop CC. For all image formats, the Background Layer was unlocked and renamed "Model Layer". A new layer was added, named "Background Layer", and moved beneath Model Layer. Using the "Paint Bucket Tool," Background Layer was selected and made black. The Model Layer was then selected. The "Eraser Tool," set at 12pt, was used to separate the image pixels being kept in the final image (pixels that make up the model and its base) from the pixels being removed (pixels that make up the background).

For image formats 1-3, the pixels that make up the model and its institutionally added base were kept. For image formats 4-8, only the pixels that make up the model were kept. For all image formats, the "Eraser Tool" was used to erase an outline around all pixels being kept. Special care was taken so no model pixels were erased. Using the "Magic Wand Tool," the now-separated background areas were selected and erased. The final image composition for images in formats 1-3 showed the isolated model and its base on a black background. The final image compositions for images in formats 4-8 showed only the isolated model on a black background (see Appendix I).

The images from all formats, background removed, were then sharpened to highlight as much visual detail as possible. The Model Layer was selected and duplicated. This duplicated layer was renamed "Layer 3." With Layer 3 selected, a "High Pass Filter" layer was applied. In the High Pass Filter window, a radius of 10.0 pixels was selected. Layer 3's "Opacity" was set to 50% and "Blending Mode" was changed to "Soft Light." Layer 3 was merged with Model Layer, sharpening the outline and details of the imaged model. When editing was completed, all images were saved as TIFF files and named following the standardized naming formats (see Appendix I).

Range of Standardized Workflow Options

To promote the implementation of this workflow across all collections, we developed a set range of standardized options for its completion. Table 4 illustrates three possible variations on our standardized method to accommodate everyone.

Discussion and conclusions

This paper presents a resource efficient, standardized method for digitizing a complete Blaschka collection. Requiring minimal special equipment, this workflow specifically offers an easy, inexpensive, and time-efficient method for

Table 4. Three workflow options for completing the standardized imaging method proposed in this paper.

STANDARDIZED OPTIONS FOR COMPLETING BLASCHKA DIGITIZATION	
Option	**Parts From Proposed Standardized Imaging Method Included**
Minimum	Use the standardized shooting setups, colour reference, and taxonomic reference methods to photograph models in formats 1, 2, 3, and 6. To save time, white card stock does not need to be applied to capture models in Format 6. Image processing and post-processing steps may be applied later, as long as the image capturing protocol has been followed.
Standard	Everything.
Optimal	Everything. After the Standard method is finalized and if resources are available, 360-degree imaging is completed for formats 3, 5, 6, and 8. In each format, images are captured at 5-degree increments for 360-degrees.

digitizing the Blaschka collections in Ireland. The results of this method are truth, digital surrogates of each NMINH model. These high-quality images can now be confidently used for model identification, comparison, assessment, and research between and across all collections. This approach is particularly beneficial for identifying hidden materials, cracks, some symptoms of glass disease, damage and deterioration without the use of advanced and expensive equipment. Hopefully, this can help inform curators and conservators when considering methods of storing, displaying, and caring for collections without unnecessary excessive handling of the models. While this method is geared towards aiding research, conservation, and curatorial efforts, the resulting high quality digital images can also be powerful visual tools for aiding public outreach, strategic communication, and museum marketing. Lastly, images of each model can be used for wide-scale, pedagogical purposes. While each model exists as a didactic object, their fragility keeps them from being accessible to large public audiences for environmental education initiatives. The models' digital surrogates can be safely and effectively disseminated globally and used as digital education tools to improve ecoliteracy.

Please note: Appendix A can be viewed fully online at: XXXXXXXXX

Acknowledgements

We wish to thank the National Museum of Ireland – Natural History staff and Keeper Nigel Monaghan for their support and allowing us to perform this work.

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Appendix I: to Recording of Blaschka glass invertebrate models: A method and workflow for imaging using standardized methods Author(s): Whitman, J., Viscardi, P., & E.G. Reynaud
Source: Whitman, J. D., Viscardi, P., and Reynaud, E. G. 2022. Recording of Blaschka glass invertebrate models: A method and workflow for imaging using standardized methods. *Journal of Natural Science Collections.* **10.** pp. 115-XX.
URL:

Table S1 – Photography Equipment & Software

EQUIPMENT	
QUANTITY	**TYPE**
1	Sony Cyber-Shot DSC-RX10 II digital camera with attached Carl Zeiss 24-200mm f/2.8 lens (35mm eq.)
1	Studio tripod
2	7' light stands
2	10" diameter aluminium reflectors
2	135W 5500K CRI ≥ 95 Daylight Balanced CFL Photography Light Bulb
1	30" x 30" x 30" table for shooting
1	60" x 36" x 30" industrial worktable
1	24" x 24" x 24" tabletop photo studio lighting soft box shooting tent with white and black backdrops
2	Clear 1/8" thick acrylic Plexiglas plastic risers (3" x 3")
2	Clear 1/8" thick acrylic Plexiglas plastic risers (6" x 6")
1	22" x 22" x ¼" clear acrylic Plexiglas plastic sheet
-	Card stock (white and black)
1	X-ACTO knife
2	Metric rulers
6	4.5" photography spring clamps
2	Plain matte tablecloths (white and black)
3	Sandbags (5-10lb)
1	18% grey card
1	X-Rite ColourChecker Passport Photo 2 Target
SOFTWARE	
1	X-Rite ColourChecker Passport Photo 2 Camera Calibration Software
1	Adobe Camera Raw
1	Adobe Photoshop CC

Figure S1: Setup

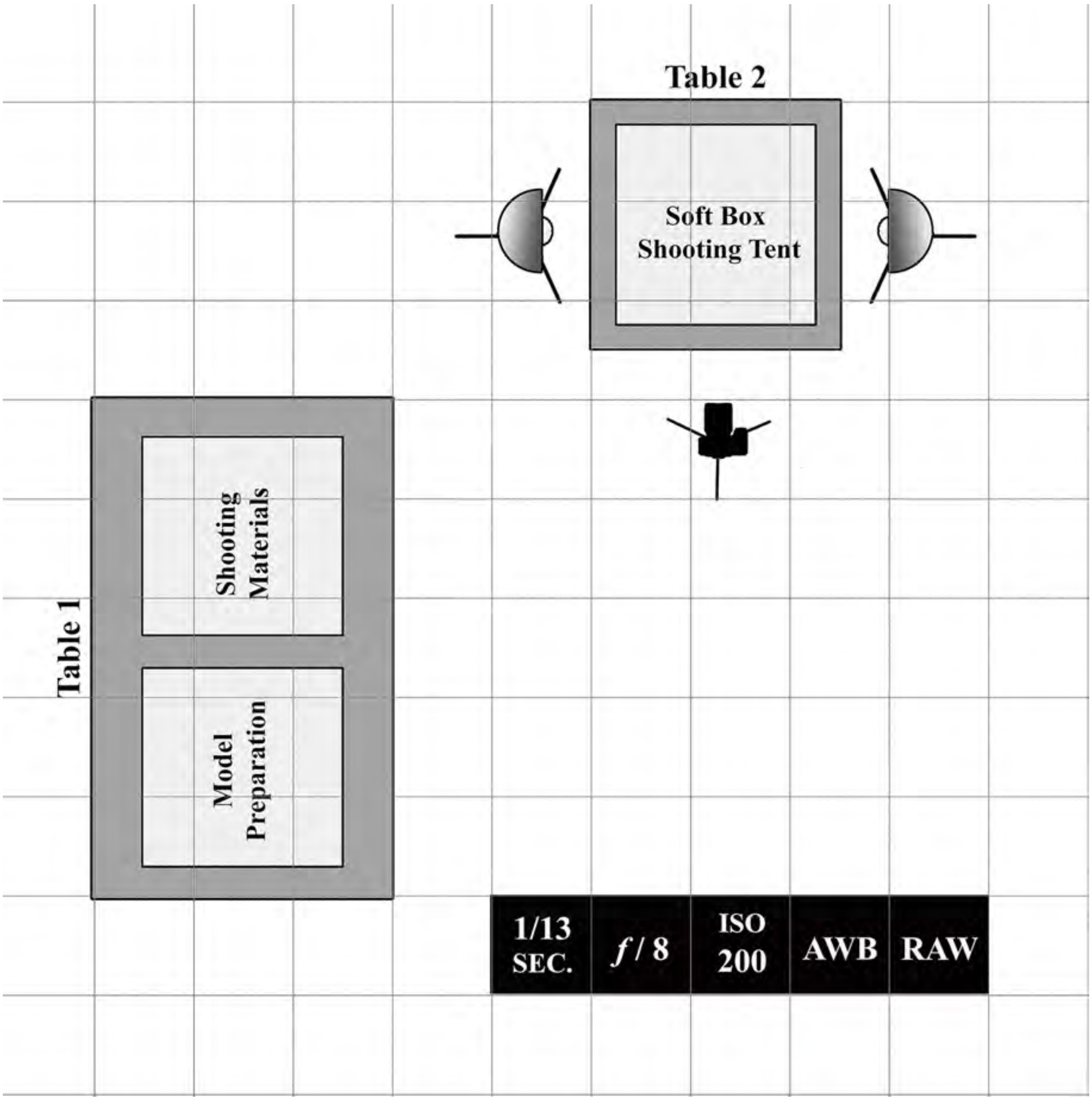
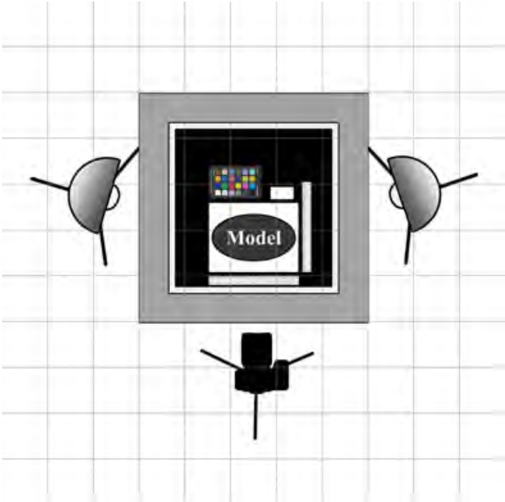
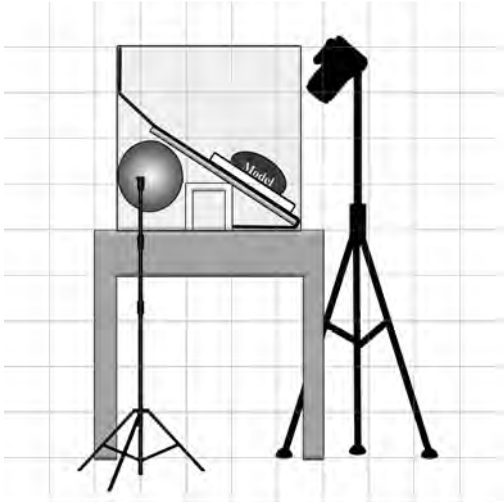


Table S2: Taxonomic Reference Image Formats 1-6

FORMAT 1: REFERENCE IMAGE

SHOOTING SETUP DIAGRAMS



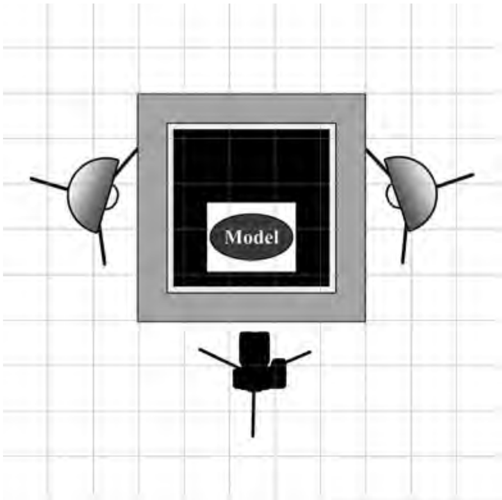


Shooting Setup Description

A 6” riser was placed in the center of the tent. Plexiglas sheet was securely leaned against the riser, its front edge bolstered by the front of the tent. Black backdrop, used to subdue any colour cast, was secured to the tent, then draped over the Plexiglass sheet and tucked under the front of the sheet. Model was carefully placed on the bottom half of the Plexiglas sheet. If a model was larger and required more stability from the Plexiglas sheet, a second 6” riser was added next to and centered with the first riser to add support. Rulers were set along the bottom and right side of the model. Information card and target were organized near the model so all objects could be captured in the image frame. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. Tripod was adjusted so the model could be photographed straight-on in dorsal view.

Initial Format Image - Unprocessed	Final Format Image - Processed
	

Table 2: Taxonomic Reference Image Formats 1-6

<table>
<tr><th colspan="2">FORMAT 2: MUSEUM PLAN VIEW</th></tr>
<tr><th colspan="2">SHOOTING SETUP DIAGRAMS</th></tr>
<tr><td colspan="2">

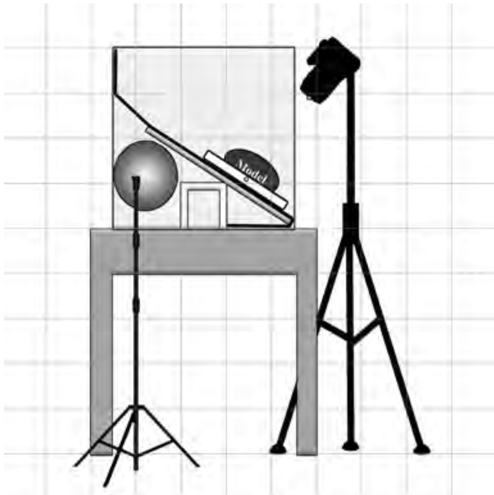
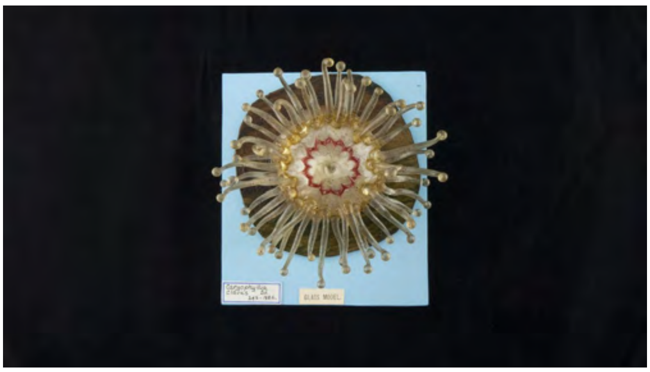

</td></tr>
<tr><th colspan="2">Shooting Setup Description</th></tr>
<tr><td colspan="2">A 6” riser was placed in the center of the tent. Plexiglas sheet was securely leaned against the riser, its front edge bolstered by the front of the tent. Black backdrop, used to subdue any colour cast, was secured to the tent, then draped over the Plexiglass sheet and tucked under the front of the sheet. Model was carefully placed on the bottom half of the Plexiglas sheet. If a model was larger and required more stability from the Plexiglas sheet, a second 6” riser was added next to and centered with the first riser to add support. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. Tripod was adjusted so the model could be photographed straight-on in dorsal view. Center of the camera’s lens was aligned with the center of the model’s base.</td></tr>
<tr><th>Initial Format Image- Unprocessed</th><th>Final Format Image - Processed</th></tr>
<tr><td></td><td></td></tr>
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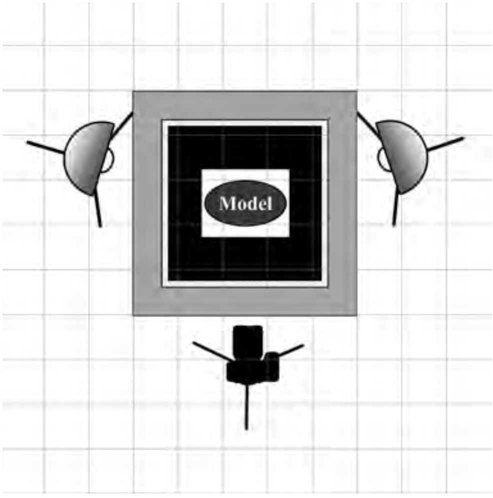
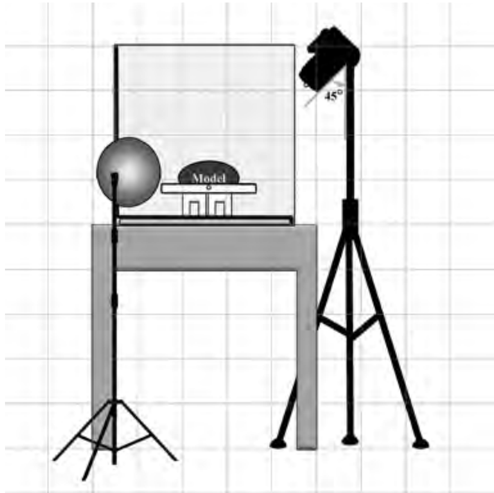
Table 2: Taxonomic Reference Image Formats 1-6

FORMAT 3: MUSEUM 45-DEGREES

SHOOTING SETUP DIAGRAMS





Shooting Setup Description

Plexiglas sheet was set flat on the bottom of the tent. Black backdrop, used to subdue any colour cast, was secured to the tent, then draped over the Plexiglas sheet. A 3" riser was placed in the center of the Plexiglas sheet. Model was carefully positioned on the riser, with the front side facing the camera first. If a model was larger and required more stability from the riser, a second 3" riser was added next to and centered with the first riser to add support. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. Camera was fixed on the tripod at 45-degrees and the center of the lens was aligned with the center of the model's base.

Initial Format Image- Unprocessed	Final Format Image - Processed
Front	
	

Table 2: Taxonomic Reference Image Formats 1-6 (Format 3 continued)

FORMAT 3: MUSEUM 45-DEGREES (Continued)	
Right	
	
Back	
	
Left	
	

Table 2: Taxonomic Reference Image Formats 1-6

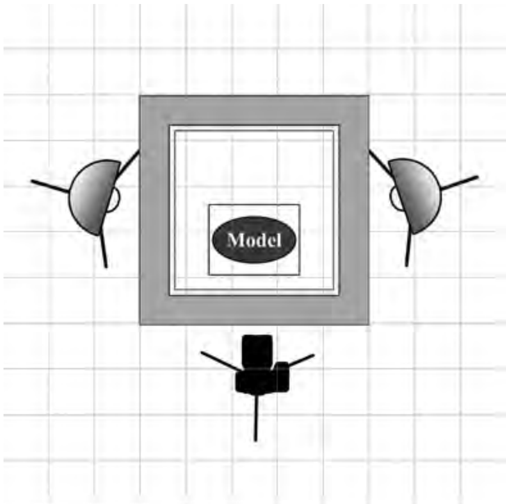
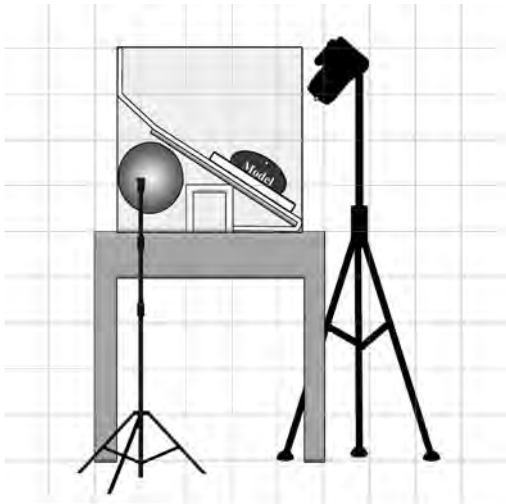
FORMAT 4: WHITE PLAN VIEW	
SHOOTING SETUP DIAGRAMS	
	
Shooting Setup Description	
A 6" riser was placed in the center of the tent. Plexiglas sheet was securely leaned against the riser, its front edge bolstered by the front of the tent. White backdrop was secured to the tent, then draped over the Plexiglass sheet and tucked under the front of the sheet. Before moving the model to the shooting setup, its base was completely and carefully covered in white card stock. Model was then carefully placed on the bottom half of the Plexiglas sheet. If a model was larger and required more stability from the Plexiglas sheet, a second 6" riser was added next to and centered with the first riser to add support. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. Tripod was adjusted so the model could be photographed straight-on in dorsal view. Center of the camera's lens was aligned with the center of the model.	
Initial Format Image- Unprocessed	**Final Format Image - Processed**
	

Table 2: Taxonomic Reference Image Formats 1-6

<table>
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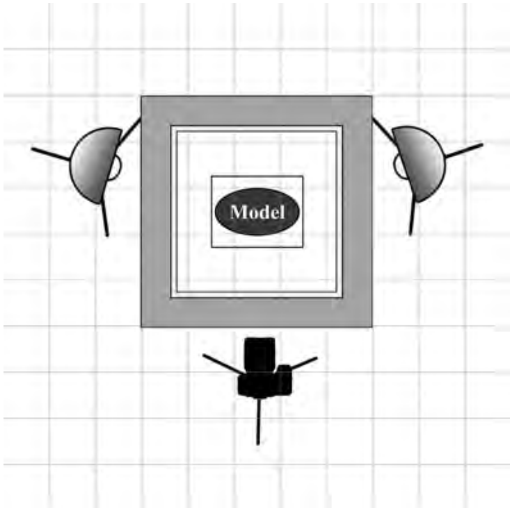
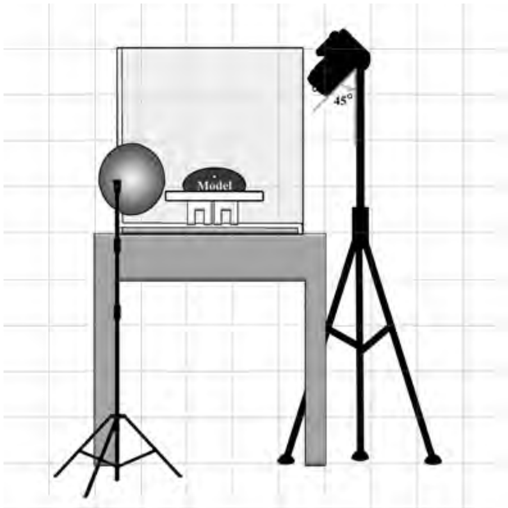
<tr><td>
</td><td>
</td></tr>
<tr><th colspan="2">Shooting Setup Description</th></tr>
<tr><td colspan="2">Plexiglas sheet was set flat on the bottom of the tent. White backdrop was secured to the tent, then draped over the Plexiglas sheet. A 3” riser was placed in the center of the Plexiglas sheet. Model, its base still covered in white card stock, was carefully positioned on the riser, with the front side facing the camera first. If a model was larger and required more stability from the riser, a second 3” riser was added next to and centered with the first riser to add support. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. Camera was fixed on the tripod at 45-degrees and the center of the lens was aligned with the center of the model.</td></tr>
<tr><th>Initial Format Image- Unprocessed</th><th>Final Format Image - Processed</th></tr>
<tr><th colspan="2">Front</th></tr>
<tr><td></td><td></td></tr>
</table>

Table 2: Taxonomic Reference Image Formats 1-6 (Format 5 continued)

FORMAT 5: WHITE 45-DEGREES (Continued)	
Right	
	
Back	
	
Left	
	

Table 2: Taxonomic Reference Image Formats 1-6

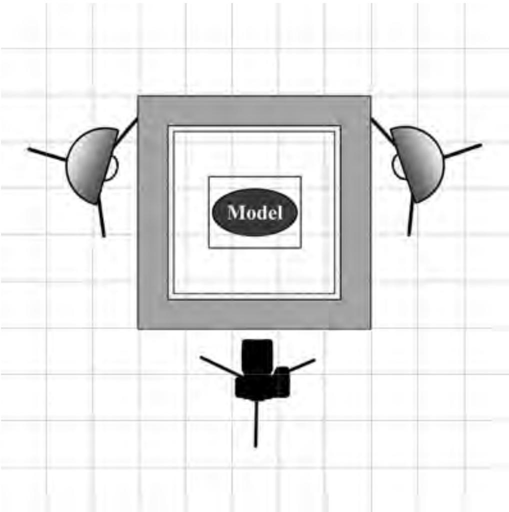
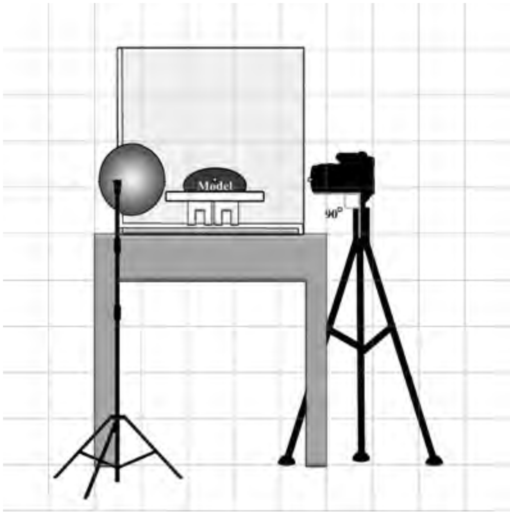
<table>
<tr><th colspan="2">FORMAT 6: WHITE 90-DEGREES</th></tr>
<tr><th colspan="2">SHOOTING SETUP DIAGRAMS</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th colspan="2">Shooting Setup Description</th></tr>
<tr><td colspan="2">Plexiglas sheet was set flat on the bottom of the tent. White backdrop was secured to the tent, then draped over the Plexiglas sheet. A 3” riser was placed in the center of the Plexiglas sheet. Model, its base still covered in white card stock, was carefully positioned on the riser, with the front side facing the camera first. If a model was larger and required more stability from the riser, a second 3” riser was added next to and centered with the first riser to add support. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. The camera was fixed on the tripod at 90-degrees and the center of the lens was aligned with the center of the model.</td></tr>
<tr><th>Initial Format Image- Unprocessed</th><th>Final Format Image - Processed</th></tr>
<tr><th colspan="2">Front</th></tr>
<tr><td></td><td></td></tr>
</table>

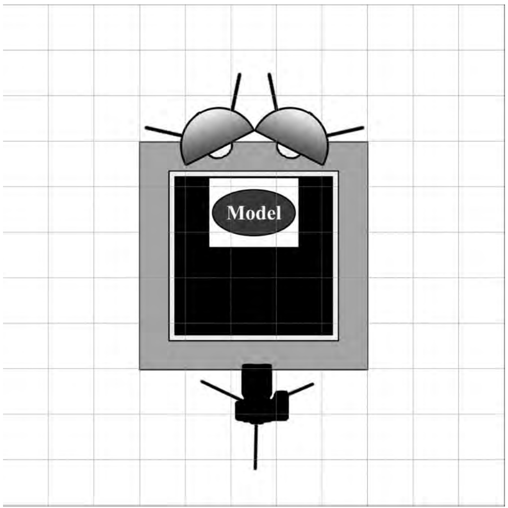
Table 2: Taxonomic Reference Image Formats 1-6 (Format 6 continued)

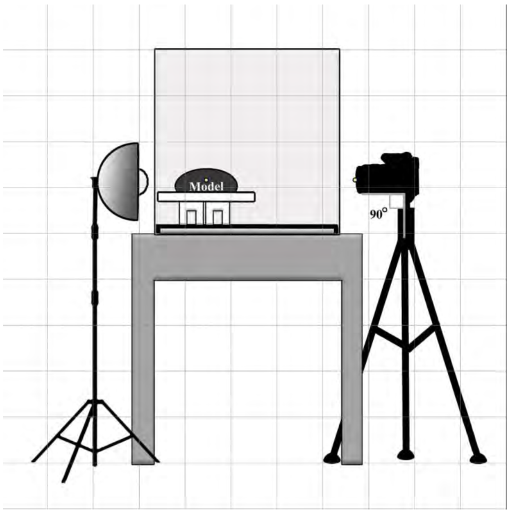
FORMAT 6: WHITE 90-DEGREES (continued)	
Right	
	
Back	
	
Left	
	

Table S3: Damage Reference Image Formats 7-8

FORMAT 7: BACKLIT 90-DEGREES

SHOOTING SETUP DIAGRAMS





Shooting Setup Description

Plexiglas sheet was set flat on the bottom of the tent. Black backdrop was used to cover the tents left side, right side, and base. No backdrop was used on the back side of the tent. A 3" riser was placed in the center back of the Plexiglas sheet. Model was carefully centered on the riser, with the front side facing the camera first. If a model was larger and required more stability from the riser, a second 3" riser was added next to and centered with the first riser to add support. Model and the riser(s) were moved together and positioned as close to the back wall of the tent as possible. Both light stands were moved to the back side of the tent and positioned so the lights were two inches away from the tent. Heights and orientation of both lights were adjusted to line up with the center of the model. Camera was fixed on the tripod at 90-degrees and the center of the lens was aligned with the center of the model. Backlighting the model through the tent exposed the model's structural components and damage.

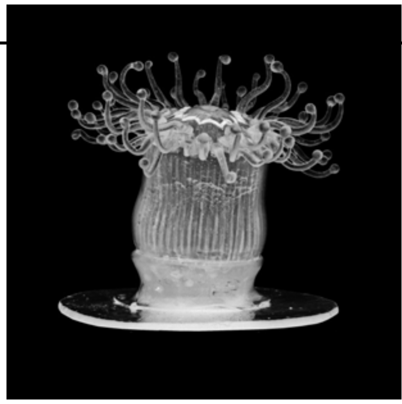
Initial Format Image- Unprocessed	Final Format Image - Processed
Front	
	

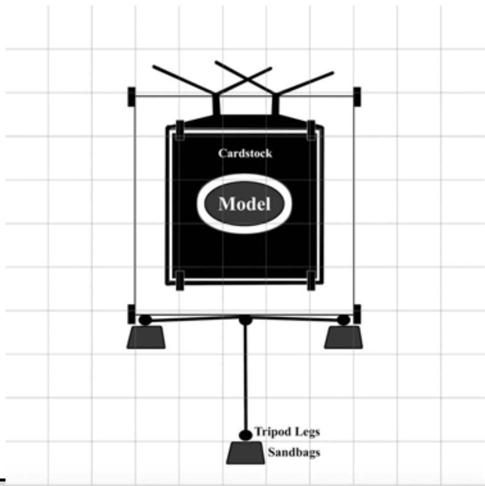
Table S3: Damage Reference Image Formats 7-8 (Format 7 continued)

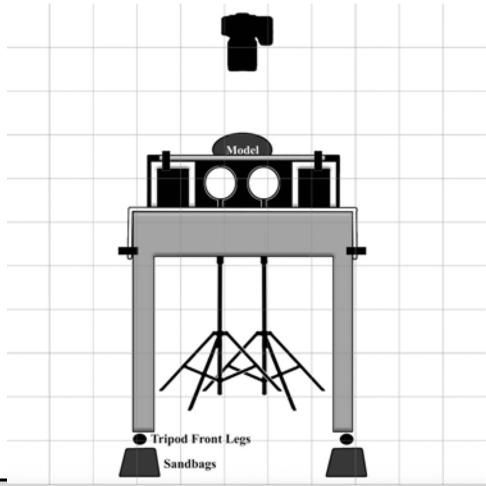
FORMAT 7: BACKLIT 90-DEGREES (Continued)	
Right	
	
Back	
	
Left	
	

Table S3: Damage Reference Image Formats 7-8

FORMAT 8: UNDERLIT PLAN VIEW

SHOOTING SETUP DIAGRAMS





Shooting Setup Description

The model was photographed in dorsal view, while underlit with high intensity light. This method was only used for models that were not attached to a base and could be moved without causing damage. *Shooting Setup:* Tent was not used in this setup. Shooting table was covered in a white tablecloth and secured in place with four clamps. Two 6" risers were placed on the table fourteen inches apart. Plexiglas sheet was set securely on the two risers. Aluminium reflectors were taken off of the light stands. Both light stands were moved to one side of the table and their heights were adjusted for the lights to fit, side by side, between the risers under the Plexiglas sheet. Black backdrop was secured with clamps around the sides of the Plexiglas sheet, trapping the light. Tripod was positioned on the side of the table opposite from the light stands. Tripod's front two legs were leaned against the table and sandbags were set at the base of all three legs. Camera was fixed on the tripod directly over the shooting setup so the model could be shot safely in dorsal view . If resources are available to procure more equipment, an overhead camera mount, glide gear, or modular overhead camera and lighting rig are recommended. Once everything was in place, the model was carefully moved to the center of the Plexiglas. Black card stock was arranged around the model to direct and centralize the light. Underlighting the model exposed the model's structural components and damage. *Notes*: Plexiglas was cleaned before/ after each model was photographed. To avoid the Plexiglas heating and damaging the models, the photography lights were only turned on when the model was in position, and they were turned off immediately following image capture. If using LED lighting heat is less of a concern, but require more post-processing of the images due to the colour temperature. Setting up the shooting area and all model preparation was completed with the studio lights on.

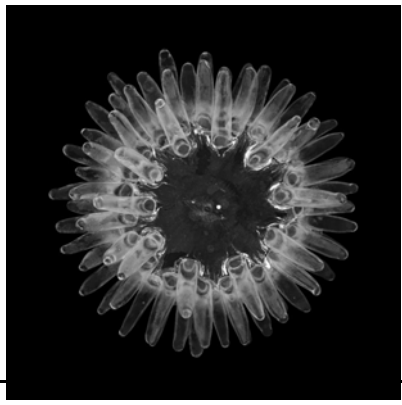
Initial Format Image- Unprocessed	Final Format Image - Processed
	

Table S4 – Range of Standardized Workflow Options

RANGE OF STANDARDIZED WORKFLOW OPTIONS	
Option	**Parts From Proposed Standardized Imaging Method Included**
Minimum	• Shooting setups • colourColour reference • Taxonomic reference • Formats 1, 2, 3, and 6. To save time, white card stock does not need to be • applied to capture models in Format 6.
Standard	• Shooting setups • Colour reference • Taxonomic reference • Formats 1, 2, 3, and 6. To save time, white card stock does not need to be • applied to capture models in Format 6. • All image processing and post processing steps
Optimal	• Standard Option. • After the Standard Option is finalized and if resources are available, 360-degree • imaging is completed for formats 3, 5, 6, and 8. • In each format, images are captured at 5-degree increments for 360-degrees.

Image File Formatting

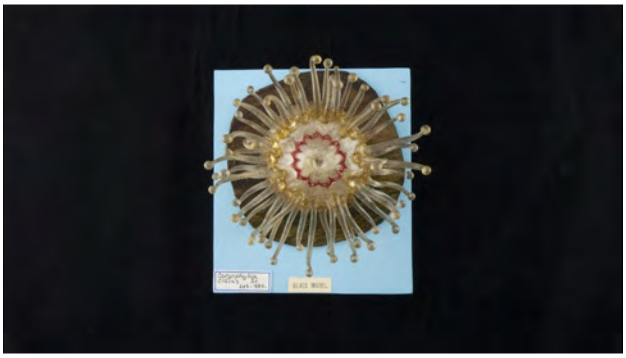
STANDARDIZED IMAGE FILE NAMES FOR HDs		
IMAGE TYPE	**File Name Format**	**Example (model: 1886.751.1)**
Reference Image	NH#_R	1886-751-1_R
Museum Plan View	NH#_MP	1886-751-1_MP
Museum 45°	NH#_M45[F, B, R, L]	1886-751-1_M45F
White Plan View	NH#_WP	1886-751-1_WP
White 45°	NH#_W45[F, B, R, L]	1886-751-1_W45B
White 90°	NH#_W90[F, B, R, L]	1886-751-1_W90R
Back-Lit Plan View	NH#_BLP	1886-751-1_BLP
Back-Lit 90°	NH#_BL90[F, B, R, L]	1886-751-1_BL90L
***[F,B,R,L] directions are based on museum mount. *Dots in museum numbers replaced with ‘ - ’. *Spaces replaced with ‘ _ ’.**		

TIME TO PHOTOGRAPH PER MODEL/BATCH		
IMAGE TYPE	**1 MODEL** (minutes)	**5 MODELS/1 BATCH** (minutes)
Reference Image & Museum Plan View	8	40
Museum 45°	10	50
White Plan View	6	30
White 45°	10	50
White 90°	10	50
Back-Lit Plan View	5	25
Back-Lit 90°	5	25
White Out Museum Board	10	50
Total Set Up Time for All Image Types	20	
TOTAL	**84**	**340**
*Time is completely dependent on the type of model being photographed. These times are averages of recorded times from multiple model types.		

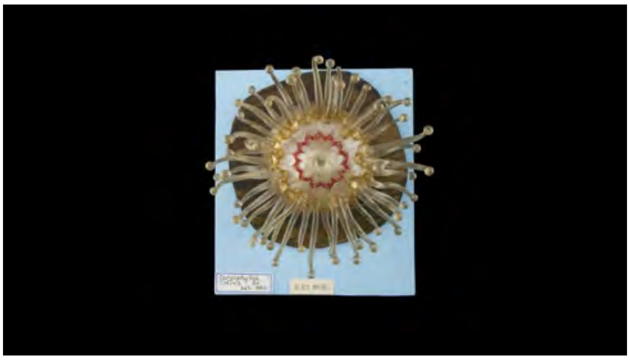
IMAGE POST PROCESSING USING COLOURCHECKER PASSPORT AND ADOBE PHOTOSHOP CC
Two image files are needed for the editing process: 1. The RAW file showing the model, model information, and colourchecker tablet. 2. The RAW file showing just the model.
Steps to develop an accurate colour profile:
• Drag image file 1 into Photoshop CC 2017 so that Camera RAW opens up. • Select the White Balance Tool in the dialog box and click the white square on the colourchecker tablet. • Click 'save image' and save file as a DNG. • Open ColourChecker Passport and drag the DNG image into the drop window. • Align the green grid system with the colourchecker tablet in the DNG image. • Click 'Create Profile'. Save profile to the 'Camera Profiles' folder – use the model number as the profile file name.
Steps to edit the final image:
• Drag image file 2 into Photoshop CC 2017 so that Camera Raw opens up. • Click on the Camera Calibration icon. • Select your recently saved profile from the Camera Profile drop down tab. • Click 'Open Image'. • Unlock the Background Layer and rename it Model Layer. • Add a new layer, name it Background Layer, and place it beneath Model Layer. • Using the Paint Bucket Tool, make Background Layer black. • Select Model Layer and the Eraser Tool. • Using a 12px size eraser, trace around the entire outline of the model, separating the background pixels from the model pixels. Zoom in on the image so that you can erase as close to the model pixels as possible. • Using the Magic Wand Tool, select and erase the remaining background pixels. The resulting image • should be just the isolated model on a black background. • Save image file.
Steps to sharpen Model Layer in final image:
• Select and duplicate Model Layer to make Layer 3. Select Layer 3. • Under Filter, then Other, select High Pass. • In the High Pass Filter window, select a radius of 10.0 pixels. Press OK. • Change Layer 3's Opacity to 50% and the Blending Mode to Soft Light. • Merge Model Layer with Layer 3. • Save image file.

TIMES FOR POST PROCESSING PER IMAGE TYPE	
IMAGE TYPE	**1 MODEL** (minutes)
Reference Image	5
Museum Plan View	10
Museum 45° - Front	30
Museum 45° - Back	30
Museum 45° - Right	30
Museum 45° - Left	30
White Plan View	40
White 45° - Front	40
White 45° - Back	40
White 45° - Right	40
White 45° - Left	40
White 90° - Front	40
White 90° - Back	40
White 90° - Right	40
White 90° - Left	40
Back-Lit Plan View	40
Back-Lit 90° - Front	40
Back-Lit 90° - Back	40
Back-Lit 90° - Right	40
Back-Lit 90° - Left	40
White Out Museum Board	40
TOTAL	**735**
*Time is completely dependent on the type of model being processed. These times are averages of recorded processing times from multiple model types. These times were recorded by a professional editor who completed the post processing steps on a MacBook Pro (Operating System: macOS Big Sur Version 11.6. Processor: 2.4 GHz 8-Core Intel Core i9).	

Other possible ways to show process on the following pages

TAXONOMIC REFERENCE. IMAGE FORMAT 2: MUSEUM PLAN VIEW – FULL PROCESS		
IMAGING	Colour reference snapshot	
	Model imaged in Format 2	
PROCESSING	Colour profile applied.	

Other possible ways to show process on the following pages (Continued)

<table>
<tr><th colspan="3">TAXONOMIC REFERENCE. IMAGE FORMAT 2: MUSEUM PLAN VIEW – FULL PROCESS (CONTINUED)</th></tr>
<tr><td rowspan="2">POST PROCESSING</td><td>Background information removed.</td><td></td></tr>
<tr><td>High Pass Filter Layer applied.</td><td></td></tr>
<tr><td>FINAL IMAGE FILE</td><td colspan="2">
</td></tr>
</table>

NatSCA AGM 2021

1.50pm, Thursday 27th May 2021, 1.50pm

Zoom

Attendees

Jack Ashby, Clare Brown, Amanda Callaghan, Jennifer Gallichan, Isla Gladstone, Yvette Harvey, Kirsty Lloyd, Lucie Mascord, Holly Morgenroth, Bethany Palumbo, Glenn Roadley, Paolo Viscardi, Donna Young.

1. Apologies for absence

Jan Freedman, David Gelsthorpe.

2. Matters arising from Minutes of AGM Thursday 14th May 2020

The meeting was held on Zoom as published in *Journal of Natural Science Collections* **8**: 73-83 (2021).

Proposal to accept the minutes of the 2020 AGM, including any amends from matters arising, as an accurate record:
Proposer: Simon Moore Seconder: Laura McCoy

3. Secretary's Report: Yvette Harvey

Nine Zoom committee meetings have been held since the last AGM. Trustees have faced challenges at work and home over the past year due to the global pandemic, affecting meeting attendance. Please see below (- denotes special leave):

	18.vi. 2020	30.vii. 2020	27.viii. 2020	24.ix. 2020	29.x. 2020	17.xii. 2020	21.i. 2021	25.ii. 2021	22.iv. 2021
Jack Ashby	y	y	y	y	y	y	y	Y	y
Clare Brown			y	y		y		Y	y
Amanda Callaghan		y			y		y		
Jan Freedman					y				
Jennifer Gallichan	y		y	y	y	y	y	Y	y
David Gelsthorpe	y	y	y	y	y	y	y	Y	y
Isla Gladstone	y	y	y	y	y	y	y	Y	y
Yvette Harvey	y	y	y	y		y	y	y	y
Kirsty Lloyd	_	_	_	_	_	_	y	y	y
Lucie Mascord	y	y			y		y	y	y
Holly Morgenroth	y			y	y	y	y	y	y
Bethany Palumbo	y	y	y	y		y	y	y	
Glenn Roadley	y			y	y	y	y	y	y
Paolo Viscardi	y			y	y		y	y	
Donna Young	y	y	y	y	y	y	_	_	_

4. Treasurer's Report: Holly Morgenroth

Accounts summary 01.02.2020 - 31.01.2021

Income	2020-2021		2019-20
Institutional Subscriptions			
Previous Years	80		239
Current Year (bank)	2,624		1,942
Current Year (PP)			39
Future Years	40		-
		2,744	**2,220**
Personal Subscriptions			
Previous Years	64		180
Current Year	5,087		3,817
Current Year (PP)			68
Future Years	113		60
		5,265	**4,125**
Workshop Income			
Entomology	75		1,645
Basics 2020	1,279		780
			2,144
		1,354	**4,569**
Conference Income			
2019	780		10,992
2018	-		22
		780	**11,014**
Donations			
Donations	19		
		19	
Other			
Misc.	-		94
Bank interest	17		45
		17	**139**
TOTAL INCOME		**10,179**	**22,067**

Expenditure	2020-2021		2019-20
Running costs			
Committee Expenses	- 537		- 4,244
Website	- 867		- 459
Stationery	- 73		- 5
Postage	-		-
Data Protection	- 35		- 35
		- 1,512	**- 4,743**
Workshops			
Conservation	-		- 209
Entomology	-		- 1,075
Basics 2020	- 437		- 582
Funding	-		- 786
		- 437	**- 2,652**
Conference			
2019	- 200		- 8,302
		- 200	**- 8,302**
Publications & Information Provision			
2018 Journal print & postage			- 1,916
2019 Journal print & postage	- 1,748		- 20
		- 1,748	**- 1,936**
Charitable			
2019 Bill Pettit Fund	- 1,840		- 1,105
Bursaries	-		- 500
Sector support	-		- 100
		- 1,840	**- 1,705**
Other			
TOTAL EXPENDITURE		**- 5,737**	**- 19,339**

OUTSTANDING EXPENDITURE		
Bill P		£ 3,524
Journal		£ 1,600
		£ 5,124
EXPECTED INCOME		
		£ -

Cash Flow Statement			
01.02.2020	Current a/c	£ 21,259	
	Deposit a/c	£ 22,475	
	Paypal a/c	£ 107	
			£43,842
31.01.2021	Current a/c	£ 10,811	
	Deposit a/c	£ 37,492	
	Paypal a/c		
			£48,303
NB Adjusted balance			£43,179
			-£ 663

Charity Commission report for signing after AGM approval

CHARITY COMMISSION FOR ENGLAND AND WALES — Natural Sciences Collections Association — 1168918

Receipts and payments accounts — CC16a

For the period from (Period start date) 01.02.2020 To (Period end date) 31.01.2021

Section A Receipts and payments

	Unrestricted funds	Restricted funds	Endowment funds	Total funds	Last year
	to the nearest £	to the nearest £	to the nearest £	to the nearest £	to the nearest £
A1 Receipts					
Institutional subscriptions	2,744	-	-	2,744	2,230
Personal subscriptions	5,265	-	-	5,265	4,123
Workshops	1,354	-	-	1,354	4,569
Conferences	780	-	-	780	11,014
Bank interest	17	-	-	17	42
Misc	-	-	-	-	91
Donations	19	-	-	19	-
	-	-	-	-	-
Sub total(Gross income for AR)	10,179	-	-	10,179	22,067
A2 Asset and investment sales, (see table).					
	-	-	-	-	
	-	-	-	-	-
Sub total	-	-	-	-	-
Total receipts	10,179	-	-	10,179	22,067
A3 Payments					
Running costs	1,512	-	-	1,512	4,743
Workshops	437	-	-	437	2,652
Conferences	388	-	-	388	8,302
Publications & information provision	1,748	-	-	1,748	1,836
Bill Pettit Memorial Fund	1,648	-	-	1,648	1,105
Bursaries	-	-	-	-	500
Sector support	-	-	-	-	100
Sub total	5,737	-	-	5,737	19,338
A4 Asset and investment purchases, (see table)					
	-	-	-	-	
	-	-	-	-	
Sub total	-	-	-	-	
Total payments	5,737	-	-	5,737	19,338
Net of receipts/(payments)	4,442	-	-	4,442	2,729
A5 Transfers between funds	- 5,000	5,000	-	-	-
A6 Cash funds last year end	43,842	-	-	43,842	41,113
Cash funds this year end	43,284	5,000	-	48,284	43,842

Section B Statement of assets and liabilities at the end of the period

Categories	Details	Unrestricted funds	Restricted funds	Endowment funds
		to nearest £	to nearest £	to nearest £
B1 Cash funds		43,284	5,000	-
			-	-
		-	-	-
	Total cash funds	43,284	5,000	-
	(agree balances with receipts and payments account(s))	OK	OK	OK
		Unrestricted funds	Restricted funds	Endowment funds
	Details	to nearest £	to nearest £	to nearest £
B2 Other monetary assets			-	-
			-	-
		-	-	-
		-	-	-
		-	-	-
		-	-	-
	Details	Fund to which asset belongs	Cost (optional)	Current value (optional)
B3 Investment assets			-	-
			-	-
			-	-
			-	-
			-	-
	Details	Fund to which asset belongs	Cost (optional)	Current value (optional)
B4 Assets retained for the charity's own use			-	-
			-	-
			-	-
	Details	Fund to which liability relates	Amount due (optional)	When due (optional)
B5 Liabilities	Bill Petit 2019	unrestricted	3,524	
	Journal 2020	unrestricted	1,600	
			-	
			-	
			-	
Signed by one or two trustees on behalf of all the trustees	Signature	Print Name		Date of approval
		Isla Gladstone		27/5/2021
		Yvette Harvey		27/5/2021

Notes:

- £5,000 moved from unrestricted to restricted to demonstrate commitment to Bill Petit award 2021.
- This financial year looks very different to those in the recent past but not unexpected for what has happened in 2020. Committee travel expenses greatly reduced, digital costs such as zoom for meetings and conferences greatly increased as you would expect.
- We are carefully considering how to use reserves going forwards.
- The anticipated change in bank account in 2020 was made impossible by HSBC's Covid ways of working. Anticipating new account by end of June 2021 at the very latest.

Accounts will be signed when agreed at AGM.

Proposer: Laura McCoy Seconder: Karen Banton

5. Membership Secretary's Report: Clare Brown

1st February 2020 - 31st January 2021

For 2020 the membership statistics are as follows:

- 362 members (56 institutional, 306 personal)
- We attracted 123 new members this year.
- 43 members did not renew their membership
- Around 85% of our membership is UK-based, we also have members in 18 other countries.
- 180 members choose to receive a hardcopy of the journal
- There were 13 free/complimentary mailings of the journal either for legal/copyright reasons or networking (British Library LDO, British Library CRO, GCG, Smithsonian Institute Library Gift and Exchanges, ACE, SPNHC, MA, Zoological Record, plus five copies to Agency for the Legal Deposit Libraries).

I must stress that these figures are as accurate as I am able to produce at the moment as there are various outstanding issues that may slightly affect them. However, these are a fair representation of the NatSCA numbers as they stood at the end of January 2021.

A truly strange year has seen a sharp increase in the NatSCA membership numbers. This was mainly due to our online conference in November where members enjoyed free access. We had nearly 70 new members join us in the two months running up to the conference on 19th November.

It has been a privilege to take over from Maggie Reilly as membership secretary this year and I would like to thank her for all her help and patient support as I find my feet. I would also like to thank Justine Aw, Glenn Roadley and Holly Morgenroth who have all been very tolerant and helpful this year.

6. Editor's Report: Jan Freedman

Volume 8 of the Journal of Natural Science Collections was published in February this year. Members who have requested the hard copy should have received it by now, if you are still waiting, please contact the secretary for a copy. The Volume is also available online and members should have received the password. Again, if anyone hasn't got the password for the online Volume 8, please contact myself.

We are working on a shorter Volume 9 which will be freely available online in the next few months. It includes articles from the November NatSCA conference 'Decolonising Natural Science Collections'. Articles for this Volume are either with reviewers or back with authors for revisions. I am pleased that it will include relevant and interesting articles for our sector as a whole.

The deadline for Volume 10 will be the end of July 2021, so please do contact me if you would like to submit an article about collections work, conservation, or engagement (editor@natsca.org). Volume 10 is scheduled to be published in both print and online versions in January 2022.

Thank you to the Editorial Board for all their assistance in finding peer reviewers: Rob Huxley, Lucie Mascord, Bethany Palumbo, Donna Young and Paolo Viscardi. A special thanks to committee members Jack Ashby and David Gelsthorpe for their support with the articles for Volume 9. Numerous reviewers have assisted and spent time to carefully go through the articles and make recommendations for changes. I am extremely grateful to them for all the time they spend on all the articles for this Journal.

The Notes and Comments online articles have been slower this year, perhaps due to furlough and redeployment as a result of Covid. Please do get in touch if you are interested in either submitting an article to the Journal or a more informal article to the NatSCA Notes & Comments.

7. Conservation Report: Lucie Mascord

In 2020 the activity of the conservation working group abated somewhat with the challenges imposed by the impact of Covid-19 on our working routines, an experience shared by all.

In January 2021 we ran the #NatSCAConservation Twitter conference, with 14 presentation running over 3 days. Our first experience with a twitter conference was a great success, and the platform allowed us to connect further than we had before. We welcomed international presenters including the Estonian Museum of Natural History and the Fundación de Historia Natural Félix de Azara in Argentina. It also gave us the opportunity to highlight the work from conservation students with an interest in natural history. We plan to publish these talks on the blog in due course.

During this year, work has also started to look at how NatSCA can advocate for the professional conservation sector in an effort to ensure we are promoting the highest standards in natural history conservation. This work will progress through 2021.

Many thanks to the conservation working group; Arianna Bernucci, Vicen Carrió ACR, Julian Carter, Gill Comerford, Natalie Jones, Nigel Larkin, Simon Moore ACR, Bethany Palumbo ACR, Victoria Purewal ACR, and Emilia Kingham, who co-organised the #NatSCA twitter conference.

8. Chair's Report: Isla Gladstone

NatSCA has worked hard over the past year to adapt our activity to the context of the global pandemic. A Risk Register compiled in June 2020 highlighted the clear need to translate the year's programme to virtual, but also to continue to deliver good member benefits to ensure our sustainability, and low cost content for accessibility. A focus for this has been the delivery of virtual and Twitter conferences which were free for members. These brought steep learning curves for us, but also high attendance figures, international reach and rich legacy content. We have also adapted committee working to virtual, meeting monthly over Zoom.

Despite trustees facing challenging circumstances during the pandemic we have also delivered NatSCA's journal (see Editor's report), the Bill Pettit Award, regular blogs, web content and social media, advice and advocacy, as well as the ongoing running of NatSCA. Unfortunately it has not been possible to deliver training this year due to capacity, but this will be a focus for next year.

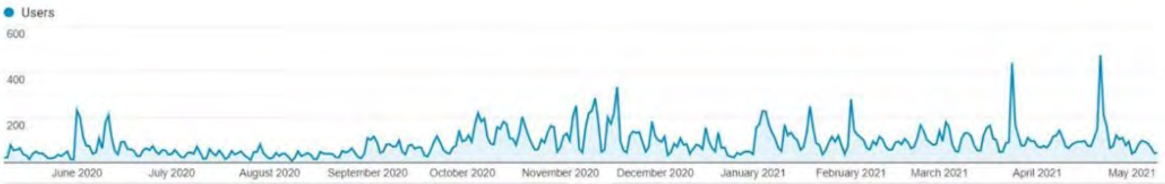
Our one-day virtual **conference** on 'Decolonising natural science collections' in November 2020 brought record figures of up to 250 attendees, with 52% not having attended a NatSCA event before and 11% international bookings. The conference was opened by a keynote talk from Miranda Lowe and Subhadra Das updating their landmark paper 'Nature Read in Black and White' – published by NatSCA in 2018 and uniquely accessed over 6,000 times to date. The conference team and speakers worked hard to translate content from our cancelled May 2020 conference to digital, and this has had good legacy including through uptake on the Museums Association's Decolonising pages. Decolonising, anti-racist practice and equality, access and inclusion will be an ongoing focus for NatSCA.

We also delivered our first ever **Twitter conference** (see Conservation Report)**,** and are pleased to be bringing you the second part of our cancelled 2020 conference in May 2021, this time with a focus on environmental crisis, and augmented with some fantastic virtual tours and lightening talks.

Partly as a result of reduced spend on committee travel we have been able to increase our **Bill Pettit Award** for this year. Co-ordinator David Gelsthorpe shares: 'NatSCA was delighted to be able to support three natural science collections projects for a record total of £5,675 in 2021. The projects that support collections care, access and engagement are: Conservation of a Bateman Ichthyosaur specimen at Sheffield Museums Trust, River Otter Beaver Taxidermy at the Royal Albert Memorial Museum, Exeter and improving storage and accessibility of the Marvellous Molluscs at the University of Aberdeen. The challenges of the COVID crisis have meant that the two projects funded in 2020 have been delayed, but are likely to restart shortly.' Committee will be continuing to meet mostly virtually, reducing running costs which we can then pass on as benefits or savings to members.

We have seen good use of our **website**, with Glenn Roadley reporting we have had over 24,500 users and over 53,000 unique page views. Our most viewed content has been on the importance of natural science collections, decolonising (with over 5,000 unique page views of Das and Lowe's 2018 abstract page this year alone, and over 4,750 for our decolonising conference pages), jobs, journal/publications and collections care/conservation. Users were mostly from the UK and US but also from 50 countries internationally. There has been a sustained increase in website use since around September 2020.

Website data – users May 2020-21:



Our **blog** editor Jen Gallichan shares: 'The blog is continuing to gain readers, with the number of visits to our pages, and average number per day both higher compared to previous years. Total visits to blog site 2020 = 10,383 (compared to 7,609 in 2019; 36% increase). We are already on 6,111 for the first 5 months of 2021. We average between 30-40 posts per year.

As you would imagine, the highest number of visitors come from the UK, although we are attracting a good audience from our colleagues in the USA, Australia, and parts of Europe. 2020 saw increased engagement from our colleagues in Brazil, as well as increased numbers of views from colleagues in Canada, Finland, The Netherlands and Ireland.

The most viewed blog posts focus on three principal themes: decolonisation, work during Covid and conservation/collections work. Some of the most read blogs in 2020/21 are the papers and review of our decolonising conference, and decolonising-related blogs about the untold collectors behind the so-called hero collections of Wallace, the botanical collections in RHS Wisley, the East India Company museum and the trophy head collections in Great North Museum: Hancock. Our readers continue to enjoy blogs with a conservation focus, including Paolo Viscardi's miraculous revival of a frog in 'Resurrection: 101' which has been viewed 1,365 times.'

Blog data - visits to page per month (not incl. May)

Month	2020-21	2019-20
November	1573	513
December	1146	600
January	1685	718
February	1523	416
March	1360	552
April	1397	1014

Blog data—coverage

Country	2019	Country	2020
UK	6593	UK	7050
USA	2036	USA	2966
The Netherlands	343	The Netherlands	609
Australia	317	Finland	525
Germany	301	France	405
India	295	Australia	394
Ireland	237	Germany	377
France	220	Ireland	327
Canada	215	Canada	300
Finland	133	Brazil	257

We have continued to develop good relationships with the Natural History Museum London's national programmes and other key UK natural science institutions. This includes **advocacy** for the integration of wider UK natural science collections within emerging ideas around a UK Distributed System of Scientific Collections (DiSSCo) programme. We have also continued to develop our international **partnerships**, and now have a nominated SPNHC liaison (Bethany Palumbo) and will be partnering with SPNHC and the Biodiversity Heritage Library for our 2022 conference in Edinburgh.

We have written to support two **collections at risk**, and are considering how we can more proactively monitor and support wider collections, including those with no in house subject specialist. We have also supported three research grant applications and two nominations for awards.

Our **User Survey** 2020 was completed by 74 users, 82% based in the UK. This highlighted the very high value NatSCA's users place on community, networking, access to expertise and knowledge sharing. Users also asked for more training opportunities (including practical and non-specialist training), virtual events, and for NatSCA to improve networking with sector networks. We have made changes in response to the survey already, for example by providing more in depth information about our Bill Pettit grant. We'll be publishing the results and using them to help focus our activity for 2021-22.

9. Election of NatSCA committee:
Trustees form a steering committee with obligations to ensure NatSCA meets our mission, ensure good governance and conform to Charity Commission regulations.

Below are the nominees for NatSCA trustee positions standing for election at this AGM. The Membership Secretary has confirmed that those proposed, those proposing and those seconding are all current personal members of NatSCA. No term will exceed three years without re-election.

Below is the nominated candidate for Treasurer:

Nominee	Position	Proposed	Seconded
Holly Morgenroth	Treasurer	Alison Hopper Bishop	Maggie Reilly

There is one vacancy for Treasurer and one nominee.

Below are the nominated candidates standing for Ordinary Member positions on the committee:

Nominee	Position	Proposed	Seconded
Jack Ashby	Ordinary Member	Clare Brown	Mathew Lowe
David Gelsthorpe	Ordinary Member	Rachel Webster	Dmitri Logunov
Lucie Mascord	Ordinary Member	Natalie Jones	Emilia Kingham
Laura McCoy	Ordinary Member	Clare Brown	Simon Moore
Glenn Roadley	Ordinary Member	Olivia Beavers	Lukas Large
Laura Soul	Ordinary Member	Freya Stannard	Kirsty Lloyd

There are six vacancies for Ordinary Members and six nominees.

Proposal 1: we propose one 'en bloc' vote for all seven nominees (one nominee for Treasurer, six nominees for ordinary member positions).

Proposer: Karen Banton Seconder: Helen Fothergill

This was a live digital Zoom poll for only paid up individual members and with a greater than 50% vote required to accept the proposal.
Membership vote result: **Yes**

Proposal 2: all seven nominees (one nominee for Treasurer, six nominees for six ordinary member positions) to be accepted as trustees.

Proposer: Erica McAlister Seconder: Julian Carter

This was a live digital Zoom poll for only paid up individual members and with a greater than 50% vote required to accept the proposal.

Membership vote result: **Yes**

10. Any other Business

There was no other business

11. Vote of thanks

Thank you to all of our trustees for their hard work in delivering NatSCA's activity over a challenging year, but one where we have adapted and pulled together. I would like to thank our Secretary (especially for adapting to monthly meetings), Membership Secretary, Treasurer, Journal Editor and Conservation Representative for the fantastic work highlighted in their reports, and to highlight some of the work of trustees not yet named. A special thanks to Glenn Roadley for his leadership in virtual conferences, supported by Donna Young, Jack Ashby, Justine Aw and the wider conference team; Bethany Palumbo for writing up our user survey; and to Kirsty Lloyd for new ideas about supporting collections at risk.
Our training lead Amanda Callaghan will be stepping down this year due to work pressures, and I would like to thank her for valued contributions. Our collections at risk lead Kirsty Lloyd will also be stepping down due to capacity, but will be continuing to work on collections at risk for NatSCA in a volunteer role.

We have a couple of new recruits compiling our monthly newsletter 'Digital Digest', many thanks to Lily Nadine Wilks, Olivia Beavers and Glenn Roadley. Huge thanks also to our conservation working group, editorial group, and volunteers, and our wider community for all your support and input.

Finally, NatSCA would like to extend a special vote of thanks to Maggie Reilly, who was a NatSCA trustee from 2003 until last year, and our Membership Secretary for many years. Maggie is retiring today from her role as Curator of Zoology at the Hunterian Museum & Art Gallery, Glasgow. We wish Maggie all the best for her retirement, and extend special recognition for all the support she has given to the natural sciences community over the years.

12. Next AGM venue

The Society for the Preservation of Natural History Collections (SPNHC), Biodiversity Heritage Library (BHL) and NatSCA 2022 conference: **4-10th June, Edinburgh**

Close

The meeting closed at 2.20 pm.

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