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NatSCA
Natural Sciences Collections Association

The Natural Sciences Collections Association

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

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

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

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

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Journal of Natural Science Collections

Aims and scope

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

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Editorial Board

Front cover image: *Taxidermy Saint Lucia giant rice rat (*Megalomys luciae*) at the MNHN (MO-1994-1329). (Photo credit: Gitte Westergaard)*

Editorial

Jan Freedman

Welcome to Volume 11 of the *Journal of Natural Science Collections*. It has been another busy year for all of us, and I am extremely grateful to all the authors in this Volume for all their time. Each article has had so much work put into them.

Thank you as always to our Editorial Board ensuring that all articles are expertly peer reviewed and always to the highest standards: Paolo Viscardi, Bethany Palumbo and Rob Huxley. And a thank you to all our anonymous peer reviewers from museums and institutions across the globe, I am indebted to them for spending so much time on providing such thorough and detailed reviews.

This Volume can be divided into four sections; colonialism, collections research, conservation and Engagement, with a large variety of papers from national and international colleagues.

The first section focuses on colonialism in museums. **Westergaad** looks at the only two surviving specimens of the Saint Lucia giant rice rats, examining how displays should shift to focus on colonial legacies. **Kaiser *et al.*** examine how we digitize collections and their impact on addressing global inequality, and provides some guidance to assist in digitizing collections from colonial contexts.

The second section includes several papers covering research into a number of different collection types. **Taylor, Lock and Gostling** provide a detailed overview of the herbarium collection of the 19th century collector Henry Leopold Foster Guermonprez, and focuses on orchids to begin to understand more about his collection and circle. In the second article in this section, **Ryder, Sales and Fischer** examine historical osteology collections which have been used for teaching, and separated from their original labels. Using historical documents and comparative material, the specimens were identified. Next, **Harvey** provides a thoroughly researched paper investigating a large herbarium at the Royal Horticultural Society that was sold in 1856, with interesting findings of lost collectors.

Our next section includes two papers focusing on conservation. **Mahtani-Williams and Jaramillo** provide detailed results examining the effects of ambient controls to help prevent pests in a herbarium collection in the Galapagos, with a comprehensive analysis of their findings. Historical preservation techniques are important for those working with natural history collections, not only for understanding how to safely handle them, but also for any future conservation work that is carried out. **Winters** examines several dried sun fish specimens in the Naturalis Biodiversity Center, in Leiden, and undertakes research to understand how these specimens have been historically preserved.

The final section for this Volume focuses on engagement. **Hearth and Densmore** undertook several tests to 3D scan and print mineral specimens. This interesting paper looks at what worked well and what types of minerals didn't work well for 3D printing, and provides useful guidance on 3D printing for outreach events and teaching. Next, **Jackson and Green** provide an interesting summary of their project working with young people where they used satellite imagery alongside real specimens to engage people with the biodiversity crisis in a new way. Our final article by **Carter** provides an overview for a project led by an environmental activist youth group, and discusses the importance of the conservation input along with the impact of the displays created.

This Volume is full of a large variety of papers which we hope are useful for your work and provide some inspiration for future projects.

View from the Chair

Isla Gladstone, Senior Curator Natural Sciences Bristol Museums, Chair NatSCA

This year has marked NatSCA's first return to in person activity since the Covid-19 pandemic. We were pleased to partner with the Society for the Preservation of Natural History Collections for their annual conference in Edinburgh in June 2022. 'Through the door and through the web' offered an opportunity to connect with international colleagues and experience the workings of a hybrid conference. NatSCA chaired two well-received symposia, 'Civically engaged natural history museums' and 'Long time, no see: updates from the natural science collections community'. We also funded ten member bursaries.

NatSCA is now busy preparing for our 2023 conference, which will be held at The Potteries Museum & Art Gallery in Stoke-on-Trent, as well as online. Our theme 'So how do we actually do all this? Hopeful futures and turning theory into practice for big issues in natural history collections', continues our commitment to support colleagues to sustain the relevance of their collections to communities, funders and the natural environment – by platforming real case studies and practical advice.

We are also working towards returning our training programme to our pre-pandemic structure of one skills-based and one seminar-based event per year, with the added benefit of virtual delivery options. Our blog has continued with a regular series of community-created content. It is also fantastic to have this issue of the journal with lots of great articles to delve into.

NatSCA has continued to partner on two national network projects in 2022, to help share their benefits with our community. 'DiSSCo UK' (the Distributed System of Scientific Collections UK) is being co-ordinated by the Natural History Museum London and funded by the Arts and Humanities Research Council (AHRC). This project is working towards securing major investment for a UK infrastructure for digitising natural science collections – accessible to all sizes and locations of heritage organisation. 'People and Plants' is an AHRC networking project exploring the modern relevance of ethnobotanical collections, in conversation with indigenous knowledge holders, researchers and museum professionals. The project has funded NatSCA members to attend workshops and share their content on our blog.

It remains a difficult time financially for many individuals and organisations. NatSCA has increased the amount awarded and number of bursaries to support members to attend our events. We are also able to write letters of advocacy for specific collections at risk, please contact: chair@natsca.org.

In late October the NatSCA trustees met for an away day, to consider our priorities for 2023. As well as a focus on our programme, we will be reviewing our funding model to ensure we are delivering best value for our community, and creating new volunteer positions to help increase capacity, reach and skills to deliver NatSCA's work. We will also have trustee positions available in 2023. NatSCA's strength is in being community-led, and we value your contributions towards this past and future. Many thanks to our current volunteers, trustees and everyone who has shared content or used our resources over the past year.

Colonial entanglements in extinction narratives: The afterlives of two Saint Lucia giant rice rats

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Abstract

European colonialism exposed islands to significant threatening processes that drove species to or near extinction. At the same time, they were regular sites of collecting living animals especially because of their high level of endemism. Natural history museums house animals that carry stories of colonial conquest over island ecologies. I argue that existing decolonising approaches to natural history museums do little to decolonise our human-non-human relationship with the species on display. Through a discussion of the extinction of Antillean rice rats in the Caribbean and the only two specimens remaining of the Saint Lucia giant rice rat (*Megalomys luciae* (Fortsyth Major, 1901)), I emphasise the importance of connecting extinction narratives to the colonial causes of their disappearance. Three lessons follow to show how natural history museums can address their inherited colonial legacies in displaying extinct animal remains collected from colonised lands.

Keywords: Animal remains, endemic rats, anthropogenic extinction, museums, decolonisation, giant rice rats

Erasing colonial extinctions from public narratives

When the Grand Gallery of Evolution at the Muséum national d'Histoire naturelle in Paris reopened in 1994, its former bird gallery was transformed into the Room of Endangered and Extinct Species. The original interior dating back to the late nineteenth century remains in place, but the specimens now filling the cabinets are either extinct or threatened, with extinction classified according to area of geographical origin: France, tropical rainforests or islands. Over two hundred animals and plants are gathered here, testifying to the mass-extinction event that we are currently witnessing.

Most of the specimens on display link directly to French overseas colonial activities, yet there is very little recognition on the display labels of the connection between these activities and the extinction of the species, nor is there recognition of France as a former imperial power over these habitats. It corresponds with Anna Guasco's (2020, p. 11-12) observation of extinction narratives in the *Survival Gallery* at the National Museum of Scotland: 'although many of the endangered species discussed are from biodiversity "hotspots" in the Global South, topics such as the Global North's or former imperialist nations' ecological debt towards these areas are not addressed'.

It is only within the last few years that scholars and museum practitioners have started to analyse the colonial legacy of natural history museums. Subhadra Das and Miranda Lowe (2018, p. 8) uncovered how natural history museums convey a 'covert racism' by only including the contribution of white people to Western science, thereby alienating certain museum visitors from natural history museums. Such erasure of the colonised manifests itself through historical collections of plants (Kaiser, 2022), minerals (Gelsthorpe, 2021) and animals (Ashby and Machin, 2021; Middleton, 2021), examples that all show how the collecting of natural history specimens from former European colonies both oppressed people and relied on local and Indigenous people's knowledge that remain unrecognised in natural history museums.

To decolonise natural history museums, Das and Lowe argue (2018, p.11) that museum professionals 'need to do better at acknowledging past wrongs for what they are, and telling the whole of the story of science'. Ashby (2021, p. 35) makes a valuable remark in his analysis of the displays of Australian fauna, when noticing that 'decolonisation in museums is most commonly applied to human stories', despite the fact that colonisation has also impacted nature and how we relate to it (Plumwood, 2003). Decolonial approaches which focus mainly on how to make natural history museums more inclusive and diverse for people overlook the potential to change and challenge our relation to the natural world. As a counter to this approach, Guasco (2020, p. 15) proposes an inclusion of 'multispecies justice museum storytelling' into displays of extinctions. This has potential for addressing the museums' responsibility to inform the visitors about colonial oppression of island ecologies as stewards of some of the only surviving remains of now extinct endemic species.

Since they hold some of the only remains of past natures that existed in former colonies prior to European colonisations, it can seem peculiar that natural history museums do not address the damage of ecological systems caused by European extractive systems, especially because natural history museums themselves carry a colonial legacy of collecting and displaying animals from oppressed nations. One reason that Ashby and Machin (2021, p. 45) identify in their article on legacies of colonial violence in natural history museums is that certain objects, such as trophy specimens associated with game hunting, 'undermine museums' conservation messages'. They are therefore often removed from public displays instead of reinterpreted from decolonial perspectives (2021, p. 45). By applying frameworks from postcolonial ecocriticism or postcolonial environmental humanities, which brings 'postcolonial and ecological issues together as a mean of challenging continuing imperialist modes of social and environmental dominance' (Huggan and Tiffin, 2015, p. 2), museums could interrogate their inherited coloniality also when it comes to the display of lost natures. This is best seen with the display of the dodo as a prime example of modern extinction caused by European activity on the island of Mauritius, but often natural history museums also relate its extinction to its evolutionary development as a flightless bird (Guasco, 2020, p. 2). Postcolonial environmental humanities respond to an excessive anthropocentrism within postcolonial studies and Eurocentrism within eco/environmental studies (DeLoughrey, Didur and Carrigan, 2015, p. xiv). Thinking through museum displays as spaces with colonial legacies that have contributed to biodiversity loss might allow new extinction narratives able to nuance the visitors' understanding of the mass extinction we experience today.

In this article, I argue that existing decolonising approaches to the natural history museums do little to decolonise our relationship with the species on display. Through a discussion of the extinction of Antillean rice rats in the Caribbean as a result of European colonisations and some remnants of them preserved and displayed in Western museums, the article argues for the importance of connecting extinction narratives to the colonial causes of their disappearance. It juxtaposes the historic collecting of individuals of Antillean rice rats with the present excavation of rice rat bones among archaeological remains. The historic remains of the now extinct species are all preserved in Western museums, all collected at a time when the species were on the brink of extinction. They constitute a collection of Caribbean origin but shaped by Western scientific norms as a desire to cataloguing the entire natural world (Barrow, 2009, p. 48). On the other hand, the discovery of the bone remains, uncovered from food waste deposits at Amerindian archaeological sites, reveals a past natural and cultural Caribbean reality that no longer exists.

A colonial extinction story

The first recorded encounter by a European of an Antillean rice rat in the Lesser Antilles was the French Catholic botanist, Jean Baptiste Du Tertre 1610-1687, as described in his book, *Histoire générale des îles Saint-Christophe, de la Guadeloupe, de la Martinique et autres de l'Amérique* (1654). On his mission to the Caribbean in 1640 he encountered rice rats in great numbers on the island of Martinique. They looked vaguely like the black rats he knew from Europe but were of such great size that not even four European rats would weigh the same as one *pilori*, as he called them in his book. He described how the endemic rats served as a food source for the Amerindian population on the island and provided an account of how they prepared the rats.

They would singe off the rats' hair, then expose the rats to air overnight to get rid of their strong musky smell before boiling them (Du Tertre, 1654, p. 342; also see Allen, 1942, p. 91). Bonyhady (2019) reveals a similar relationship between First Nation Australians and the endemic long-haired rats in his book *the Enchantment of the Long-haired Rat*. He writes that 'the *majaru* [long-haired rat] enriched the Diyari's diet and constituted a great source of fat which the Diyari rubbed on their bodies to keep their skin soft … The long-haired rat probably loomed large in the cosmology of most if not all Aboriginal groups who encountered it' (2019, p. 167). The long-haired rat played a significant role in creation stories of Australia and was enchanted by some First Nation Australians as a totem animal (2019, p. 168). While there is no firm evidence that the Antillean rice rats played a similar role for the Amerindians inhabiting the Lesser Antilles, archaeological remains do suggest that particularly the Taíons 'practised animistic and cemíistic beliefs with some totemic and matrilineal remains in their social structures' (López, 2016, p. 454). But as López (p. 454) also points out, it is a difficult task to explore extinct societies when 'only archaeological remains are left and, occasionally, a few ethnohistoric ideologically-biased attestations.'

What is known about the co-existence of the rice rats and the Amerindians comes from Du Tertre's eyewitness account, and excavated bone fragments of the rice rats - with signs of butchery and burning marks - found at Amerindian archaeological sites from the 1970s to today (Wing, 2001, p. 114). This zooarchaeological material shows that 'the rice rats of the Lesser Antilles lived close to human settlements and crops areas' and that 'this tendency to commensalism was probably established since the first human occupation in the archipelago' (Durocher *et al.*, 2021, p. 441). Even though the rice rats were killed as a source for food by the Amerindians when they inhabited the archipelago 7000 years ago, the rice rats did not disappear from the archaeological record before the arrival of Europeans.

Our knowledge about the vast existence of Antillean rice rats in the Lesser Antilles comes from the fact that they constituted an essential part of the Amerindians' diet. Molecular analysis of the bones shows that the Antillean rice rats inhabited the Lesser Antilles roughly six million years ago, possibly on oceanic dispersals from South America (Brace *et al.*, 2015, p. 1, Durocher *et al.*, 2021). The rice rats lived on almost all the Lesser Antillean islands - approximately twenty different species of rice rats once existed - which makes it one of the most significant adaptive radiations within the Caribbean islands (Brace *et al.*, 2015, p. 2). Species of rice rats are still being identified from the recovered bone material of the extinct species (Turvey *et al.*, 2010; Turvey *et al.*, 2012). But it is important not to limit the bone remains either to be a story about the Amerindians' diet or the evolutionary significance of the Antillean rice rats. As Trevathan (2017,43) explains 'there is a need … for narrative and analysis to descend into the depths, to submerge in ecological devastation in the hopes of contemplating other future alternatives.' The uncovering of extinct animals among the remnants of equally extinct human populations offers insights into the natural and cultural past of the Caribbean islands - a reality that largely disappeared with European colonisations and is almost invisible in the islands today.

To return to Du Tertre's encounter from Martinique in 1640, he observed not only the endemic Antillean rice rats but also the influx of the black rats (*Rattus rattus* Linnaeus, 1758) that accompanied the European ships to the Caribbean islands (1654, p. 342). The black rat 'was feared and loathed in Europe because it was so destructive' (Bonyhady 2019, p. 13). On the ships and as unwelcomed neighbours in the colonies, rats were considered vermin that 'destroyed harvested grain and devastate food systems' (Cole 2016, p. 143). Rats of any kind had a bad reputation and it seems to have impacted the colonists' view on the endemic rice rats they encountered when colonising the Caribbean islands. The rice rat 'was said to live in burrows in the ground and against it the colonists waged war on account of its destructive habits in their plantations' (Allen 1942, p. 91). For the colonists the rice rats were not a source of food but became a pest when the Caribbean was transformed into cultivated landscapes dominated primarily by sugar canes. Eventually, it was the accidental introduction of black rats that caused the extinction of the Antillean rice rats (Turvey *et al.*, 2010, p. 767). The endemic rice rats had developed in isolation with few, if any, predators and were defenceless against the black rat that took over their habitats. As McNeill (1994, p. 317) explains, rats were in general, throughout island communities, 'the single most consequential alien intruder,' by his phrasing, 'shock troops of ecological imperialism.'

Alfred W. Crosby (1986) coined the term *ecological imperialism* in his book of the same name, arguing that the success of European imperialism was a combination of ecological factors - especially since the European imperialists broke millions of years separation between continents and introduced sudden changes into otherwise closed ecosystems (Crosby, 2004, p. 7). It trigged biological changes that were often unintended but nevertheless made the colonisation of islands easier because of the instability it wrought on the environment (Crosby, 2004, p. 192). Crosby recognised that the introduction of various invasive species played a significant role for the success of the European colonisation of island spaces, but at the same time he also exempts the colonists from the responsibility of the ecological damage they caused. Yet islands became unstable when European settlers exploited island spaces of their resources and deployed the land to produce crops for the colonising countries (McNeill 1994, p. 302). They bear the responsibility of those detrimental changes, and museums are good places to inform the public about the connections between ecological losses and Western colonial activities abroad.

Colonial collecting of living animals

Only a handful of skin-based specimens of the Antillean rice rats from Martinique, St Vincent and St Lucia exist today (Specimens are held at the following institutions: Muséum national d'Histoire naturelle 2006-187, 1979-385, 2006-188, 1994-1329, 1883-312; Naturalis, Leiden 21287.b; London Natural History Museum 1850.11.30.6, 1853.12.16.2, 1855.12.24.201, 1897.12.26.1). These specimens were collected in the nineteenth century. The species no longer existed at the levels of abundance previously observed by Du Tertre in the early seventeenth century but were now considered rare by naturalists visiting the islands (Lorvelec *et al.*, 2007: p. 301). Animals were collected to establish a taxonomy system that should "contribute to the enterprise of cataloguing the globe's flora and fauna" (Barrow 2009: p. 48). Islands were regular sites of animal collecting because of their high level of endemism. As specimens were removed from their original context and placed inside Western collections, they immediately became part of a European rational project of knowing the entire world (Mackenzie, 2009).

The skin-based specimens which are the focus of this paper, are the only two specimens of the Saint Lucia giant rice rat (*Megalomys luciae*) known to exist today. One specimen (MNHN-ZM-MO-1994 -1329) is exhibited in the Room of Endangered and Extinct Species of the *Muséum National d'Histoire Naturelle* (MNHN) in Paris. It came into the collection in 1851 and is described in the museum report, *Bulletin du Muséum National D'Histoire Naturelle,* from 1952: 'Megalomys Luciae (Forsith Major [1901]). One specimen mounted: 1 ♀ ad., brought back by M. De Bonnecourt; this animal lived in the Menagerie Jardin des Plantes from 25 August to 12 November 1851' (MNHN, 1952, p. 70) (translated from French). From this it appears that the specimen was brought or shipped to Paris alive by M. De Bonnecourt, who also contributed other specimens from the Caribbean islands to the *Muséum National D'Histoire Naturelle.* This Saint Lucia giant rice rat spent her last few months in the Ménagerie du Jardin des Plantes until she died. The dead body was afterwards handed over to the MNHN and mounted as posed taxidermy still existing today.

The second specimen of the Saint Lucia giant rice rat (NHM-1853.12.16.2) came into the collection of the National History Museum (NHM) in London in a similar way. In *The Proceedings of the Zoological Society of London* (1849, p. 105), where all the living animals that came into their collection from 1833-1965 are recorded, one Saint Lucia giant rice rat also appears. It was presented to the Royal Menagerie in London November 1849 by lieutenant R.E. Tyler. The Saint Lucia giant rice rat died in 1852 after three years of captivity in London Zoo (Flannery and Schouten, 2001). It was handed over to the British Museum, later transferring to what is now called the NHM following the establishment of that institution, where it remains today. It was not prepared as a mount but is rather a study skin.

The establishment of the zoological department of the Jardin des Plantes in Paris and the Zoological Society of London with London Zoo marks the rise of the modern zoo (Mitchell 2018, p. 418). They were both founded to foreground natural history. The scientific endeavour to classify the world's species led to the removal of exotic animals from their lands to enhance public knowledge and research. However, the display of exotic animals was not a new phenomenon. They had been around for centuries in various forms as fairs and menageries but the display of the 'wild' was often solely for entertainment before the development of the modern zoo. Menageries often had limited knowledge of the animals, their natural diets, breeding habits, natural grouping and life-styles (Hancock, 2001, p. 55), so the collected animals did not tend to live long. Western European natural history institutions were fundamentally 'grafted onto a Eurocentric and essentially English concept' of the menagerie (Hancocks 2001, p. 17), and this is apparent in that museum collections often acquired animals exhibited in menageries and zoological gardens. Natural history museums not only represent pristine nature unaffected by humans but in fact also illustrate humans' desire to manage and control nature by exhibiting animals that have been in captivity (Baratay and Hardouin-Fugier 2002, p. 9).

While zoos are often heavily involved in animal conservation projects today, historically they have also been sites of animal extinction: the last known passenger pigeon (died 1914), Carolina parakeet (died 1917) and thylacine (died 1936), were all zoo captives. Similarly, the last Saint Lucia giant rice rat to be collected is the one that died in the London Zoo in 1852. No further specimens were collected, but the species was last reported seen in 1881 (Turvey *et al.*, 2009, p. 768).

Displaying colonial animal remains in museums

MNHN in Paris exhibits a collection of endangered and extinct species in the Room of Endangered and Extinct Species. The room contains over two hundred animal and plant specimens from the three Environments - islands, tropical rainforests and France. According to Cécile Callou, scientific responsible for the vertebrate collection at the MNHN, the gallery exhibits few specimens from mainland France (Callou, *pers comms*, May 2019). This is of course related to the historical founding of the museum where specimens were first collected from all around the world, especially French possessions during the colonial era, but it also indicates the uneven geographical distribution of endangered or extinct species in the world, where an overrepresentation belongs to tropical climates and islands (Vamosi and Vamosi, 2008; Tershy *et al.*, 2015).

The Room of Endangered and Extinct Species is dark with only light shed on the specimens inside the display cases that run down the walls on both sides of the room as well as the middle section. Jørgensen has observed that 'a room with animals in glass cases is an archive of animal bodies, but it is also an archive of animals portraits' (Jørgensen, 2022, p. 362). Jørgensen compares the animal portraits in this room with portraits painted using Dutch seventeenth-century *chiaroscuro* technique, where the only light shed on the subject is from a candlelight. It draws our attention to details and stresses the fleeting nature of life that could easy be 'snuffed out.' (Jørgensen, 2022, p. 363). Even the specimens on display are at risk; if the specimen 'dies' through aging or damage, the record of the animal disappears with it. Every fifteen minutes a gigantic Renaissance clock goes off, reminding you that time is short for many of the species in this room, for some time is already out.

Within the room, the now extinct Saint Lucia giant rice rat sits upright on its hinds with its head bending forward and its forelegs folded together (Figure 1). The tail is between its legs as it sits on a small podium locked inside a wooden display case.

This Saint Lucia giant rice rat can be classified as a mounted taxidermy specimen, where the skin of the dead animal has been preserved to make it 'come alive'. The skull has been kept inside it, but the rest of its insides have been replaced with artificial material. Taxidermy literally means 'the arrangement of skin' (Poliquin, 2012, p. 10) so what the visitor sees replicates the original animal's external appearance, where only the eyes have been replaced with glass eyes. Even though the representation of it looks authentic, the taxidermy practice is not a neutral representation of an animal, but always reflects a human relation to the animal in how the skin is arranged (Alberti, 2011; Poliquin, 2012). It is a human creation of an animal and thereby also a human gaze on that animal. We can start to ask ourselves questions about the mounting choices: Why has the body been placed in an upright position on its hinds instead of all four legs? Why is the head bending down and not straight ahead? Viewers do not know the answers to these questions, but the decisions play a fundamental role in how they make meaning and respond emotionally to the animal.

The Saint Lucia giant rice rat is exhibited in a glass case with three other taxidermy mammals from the Caribbean islands: a Martinique giant rice rat (*Megalomys desmarestii* Fischer, 1829*),* which is also extinct, a Cuban solenodon (*Solenodon cubanus* Peters, 1861) that still exists in Cuba but is categorised as endangered, and a red-rumped agouti (*Dasyprocta leporina* Linnaeus, 1758) from Guadeloupe, which is categorised as least concern since they are abundant in north-eastern South America. These are all examples of the rich fauna of flightless mammals that existed within the Caribbean islands before they experienced 'the world's highest level of historical mammal Extinction' (Turvey *et al.*, 2017, p. 918), but this is not recognised alongside the display case. The display text next to the body of the Saint Lucia

Figure 1. Taxidermy Saint Lucia giant rice rat (Megalomys luciae) at the MNHN (MO-1994-1329). (Photo credit: Gitte Westergaard)

giant rice rat reads “the Saint Lucia giant rice rat disappeared under circumstances that remained unclear. The species is known only by two specimens, one of which is presented here.” [translated from French].

While it is true that the exact reason for the disappearance of the Saint Lucia giant rice rat remains unknown, there is enough archaeological evidence to connect the disappearance of the rice rats to European colonisations of the Caribbean. ‘Radiometric dates available for archaeological horizons from different islands show that many taxa definitely survived until close to the time of first European arrival in the region around 500 years ago’ (Turvey, 2010: p. 767). How colonial activities led to the extinction of many species could easily be incorporated into the display label. It gives the museum an opportunity to both discuss European colonisations, the spread of invasive species, global trade and the vulnerability of island spaces. It would also be appropriate to reveal that Saint Lucia was a French colony, which would explain why the Saint Lucia giant rice rat is still on display in France far away from its original habitat, as well as how the species was collected in the wild and spent its last years in a menagerie. The missing information about the correlation between European colonisations and the consequential extinction rate in the Caribbean shadows which anthropogenic impact caused the disappearance of the rice rats. There are limitations to what information can be included in the display label, but in the context of this gallery the museum does not seize the opportunity to explore fundamental topics that would explain why the specimen is in their collection and no longer exists in nature.

The second existing Saint Lucia giant rice rat is in the collection at the London Natural History Museum (NHM) stored in the magazine of the museum (Figure 2). If you did not know it was a Saint Lucia giant rice rat, you would not have guessed it from its appearance.

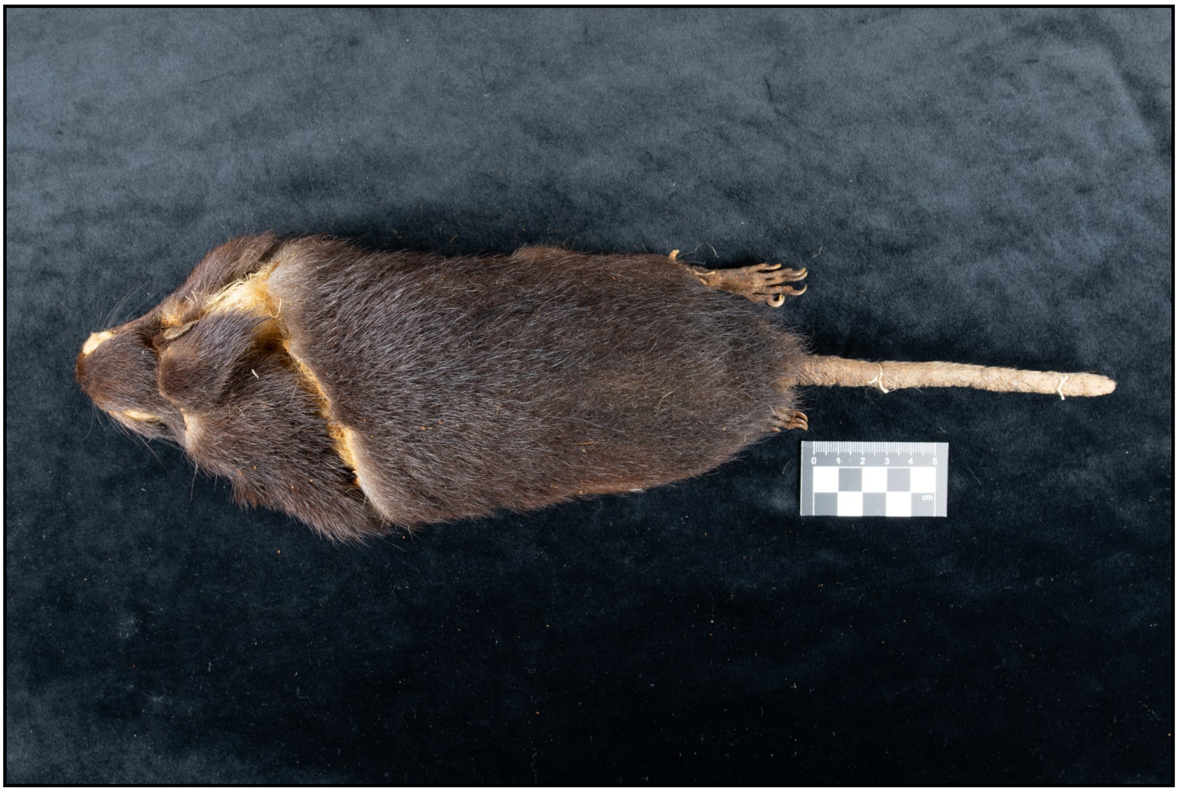

Figure 2. Front side of study skin Saint Lucia giant rice rat (Megalomys luciae) at the NHM (1853.12.16.2). (Photo credit: The Trustees of the Natural History Museum, London)

Flannery (2001) describes his encounter of this Saint Lucia giant rice rat specimen in the book, *A Gap in Nature*, where he, together with Peter Schouten, set out to create portraits of extinct animals in text and illustrations from remaining museum specimens. He writes that 'it resides in a glass-topped box in a museum drawer surrounded by hundreds of its smaller (still surviving) relatives. Whoever stuffed it did a poor job. The specimen, which is a size of a small cat, is now falling apart and is so fragile it bears a label with a strict injunction not to touch it' (Flannery and Schouten, 2001, p. 42). In contrast to the MNHN specimen, this one has been prepared as a study-skin. Since the insides of the body have been removed, the animal now exists in two parts: the skull and the skin. The study skin was what Forsyth Major (1901) used to describe the species and to give it the scientific name *Oryzomys luciae* (now considered a junior synonym) in 1901 and has since been in the hands of many scientists. Unlike the specimen displayed at the MNHN in Paris where the animal is re-animated to look alive again, this specimen is preserved only for scientific reasons.

The Saint Lucia giant rice rat has suffered significant damage as it is missing parts of the tail and forelegs. But the specimen has been CT-scanned in recent times and now exists as a 3-D model. It ensures the specimen's future existence even if its organic material should be lost. But the 3-D model also provides an 'alternative form' of the object that is not meant to replace it, but rather to give it a more dynamic life (Krupa and Grimm., 2021, p. 53). If the 3-D model is made freely available as an online source, the specimen can be shared more widely and easily as well as accessed and used in a way that is less restricted by the NMH. In that way, digital repatriation can, according to Krysiana L. Krupa and Kelsey T. Grimm, serve as a decolonising practice (2021). As it is right now, the specimen is not available for the public to see, not even as an image in the collections online.

Although the two specimens of the Saint Lucia giant rice rat are very differently preserved - one primarily for scientific research and the other specimen as an 'accurate' representation of what this specimen looked like - they are the last two skin-based remains of this extinct species. They reveal two very different means of preserving dead animals for future generations that have equally been important to how we understand the giant rice rats as well as shaping our visual impression of an ecological world that no longer exists. The specimens provide different modes for how the museum could engage themselves in the decolonisation of extinction.

Extinction narratives and colonialism

Specimens of animals have been and continue to be collected from colonised lands. Inside Western natural history museums, they are often only consulted to answer scientific questions but are silent about European colonial violence and complementary ecological devastations (Gladstone and Pearl, 2022). European natural history museums have a colonial legacy that they have just begun to engage with, with an aim of making the museums more inclusive and to break a predominating whiteness inside museum institutions (Das and Lowe, 2018), but decolonisation also concerns extinct specimens on display that have disappeared as a direct consequence of European invasion and settlements.

European colonisations have both caused the loss of nature and shaped a specific relationship to nature which is rarely visible and thereby not challenged in how natural history museums display extinction. Extinction narratives need to go beyond the individual species that are behind glass to the colonial practices that brought them there. This would shed light on past multispecies communities, an uneven loss of biodiversity and cultural practices inflicted in extinction narratives. Here, I draw out three lessons from the story of the extinction of rice rats in the Caribbean to show how European colonialism and museum display practices maintain a colonial structure inside the natural history museum. These lessons built upon Donna Haraway's concept of 'response-ability'. Haraway has defined response-ability as 'that cultivation through which we render each other capable, that cultivation of the capacity to respond' (Haraway, 2015, p. 256-257). The museums take part in this cultivation in how they create or do not create room for visitors to relate in different ways to the species on display. The museum has the responsibility to provide a space for response-ability. Inside museums, response-ability both refers to the responsibility museums have for our surrounding environment through the objects they hold in their collections but also how the museum can create room that allows for responsiveness among their visitors to environmental loss in shaping new ways of relating to the outside world (Endt-Jones, 2020, p. 186).

1. The museum has a responsibility to show different human relationships with nature than the ones formed through colonialism.

As revealed by the archaeological record, Antillean rice rats have a long history of relationships with humans. They lived near humans feeding on their crops, and the rice rats enriched the human population's diet. Their remnants bear witness to human-non-human commensalism and greater Caribbean biocultural diversity. But this historical entanglement is rarely talked about as the bone fragments are either used to understand the evolutionary history of the rice rats and their extinction or the diet of human Caribbean populations. Natural history museums miss an opportunity to reveal a different human relationship to the endemic rats that stands in contrast to how the Europeans perceived them as vermin alongside the black rat introduced into the colonies. This would challenge a dominating European value system of animals where rats are part of the 'unloved' animals that received less attention (Rose and van Dooren, 2011).

2. The museum has a responsibility to connect extinction narratives to the colonial causes of their disappearance.

The black rat was introduced to the Caribbean islands with Europeans and has been identified as the main reason for the extinction of the endemic rice rats (Turvey *et al.*, 2010, p. 767). But European colonialism is exempted from the responsibility of their extinction since the introduction of the black rats happened more by accident than as a conscious choice. This creates a narrative where the rice rats are responsible for their own extinction since they could not survive the changes imposed on their environments. If the museum instead acknowledged the impact of colonialism on the extinction of the rice rat, the uneven geographical disappearance of species would be recognised as well as the harmful effect European extractive systems had on colonised lands (Guasco, 2021).

3. The museum has a responsibility to engage their own colonial involvement in collecting and displaying foreign specimens in their collections.

When European naturalists or other settlers in the colony who took an interest in the flora and fauna started collecting specimens for Western natural history museums, the rice rats were already on the brink of extinction. A few specimens of the Antillean giant rice rats were collected from different Caribbean islands and brought 'home' to spend their last living years in zoological gardens and subsequently in Western museums. In the museum they were inscribed into a European scientific classification system in a desire to know the entire world. Few are on display; the rest are preserved in museums in countries that had the colonial power over Caribbean islands. There are no remaining specimens of the species in any of the Caribbean islands. Natural history museums are invaluable in understanding climate changes, biodiversity loss and evolutionary history of the more-than-human world (Bakker *et al*., 2020). But even though natural history museums have succeeded in making their collections relevant and useful in the present day, the historical collecting of specimens still mirrors a colonial view on the natural world that the museums must be cautious not to perpetuate and reproduce. Extinction narratives give the museum an opportunity to engage in their own colonial legacies by illuminating the connection between the specimens preserved in their collections and the biodiversity loss experienced in geographical regions of the world impacted by colonial activities.

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Promises of mass digitisation and the colonial realities of natural history collections

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Abstract

Recent debates have highlighted the colonial roots and legacies of museums, prompting intense discussions about these institutions within the museums themselves. Amidst the debates, policy-makers and museum professionals worldwide have come to regard the digitisation of collections as an important means for addressing global inequity by advancing fast and fair access to collection items. In this paper we want to caution against the hope that political problems can be solved by technical solutions alone. We argue that the digitisation of collections, like any other technology, integrates assumptions and preferences - about people, capacities, values - that, if left unchecked, reproduce or reinforce inequities. We present different approaches and initiatives developed at the Museum für Naturkunde Berlin (Natural History Museum Berlin, MfN) assessing critical questions about the assumptions and preferences congealed in digitisation efforts. What rationales and imaginaries structure digitisation? Who is served by normative concepts such as transparency, access, participation and standardisation? We argue that digitisation efforts, rather than offering a solution, provide an opportunity to consider the unequal distribution of power, historical responsibilities and epistemic injustices. This paper concludes with tentative recommendations for the digitisation of natural history collections from colonial contexts.

Keywords: colonialism, natural history objects, digitisation, public, access, racism, epistemologies, coloniality, cooperation, Museum für Naturkunde Berlin

Natural history collections and the politics of digitisation

Natural history museums consider themselves keepers of unique collections in "global custodianship" (ICOM, 2013, Sect. 4E) - accessible, usable and preserved for interested audiences and users worldwide. However, past and present analyses of museums' contents, narratives, visitors and staff structures show that they are far from being inclusive (Das and Lowe, 2018). Recent debates in civil society, media and academia have highlighted the colonial roots and legacies of museums, prompting intense discussions about these institutions also within the museums themselves (see Volumes 9, 2021, and 10, 2022 of this journal). Research on the colonial histories of collections shows that entanglement with imperial politics deeply shaped the rapid growth of natural history collections as well as logistical infrastructures and scientific practices in the field (Cornish, 2013; Callaway, 2022). These developments are part of a much broader societal and political reckoning with the enduring presence of colonial structures in modern society. The term "coloniality of power", developed by the Peruvian scholar Anibal Quijano (2007), refers to the ongoingness of epistemic, economic and political forms of extraction, violence and racism, long after imperial powers have relinquished colonial rule (Mignolo, 2007; Stoler, 2016). Much work is yet to be done to understand how "coloniality" informs natural history collections, practices of collecting, knowledge-making and collection digitisation. The fact remains that the majority of what is referred to as "cultural heritage", including natural history collections, is stored in and controlled by institutions located in imperial metropoles inaccessible to the majority of people (Duthie, 2011; Chambers *et al.*, 2016; Brusius and Singh, 2017; Gordon-Walker, 2019). In this context, many policy-makers and museum professionals regard the digitisation of collections as addressing this imbalance by advancing fast and fair access to collection items. Here, digitisation refers to making available collections or collection information in any digital form. In this sense, digitisation is seen to increase participation and advance access and scientific progress (Hahn, *et al.*, 2021; Popov, *et al.*, 2021). Thus, the discourses and practices of digitisation are tied to grand epistemic and political hopes and promises. This includes practices of digital repatriation and virtual restitution, that is, the return of digitised artefacts (Crawford and Jackson, 2020; Boast and Enote, 2013).

In Germany, technology-driven optimism has gained traction through the federal "3-road strategy". On a governmental level the cultural sector in Germany has agreed on a strategy for the digital publication of collections from colonial contexts held in Germany in a central data repository (Access-Transparency-Cooperation*,* 2020). This strategy is based on the "Framework Principles for Dealing with Collections from Colonial Contexts" which state that more transparency and documentation is needed regarding objects from colonial contexts as first steps toward addressing "the historical responsibility resulting from German colonialism and the responsibility deriving from actions marked by colonial attitudes" (Framework Principles, 2019, p.1). The framework principles further demand museums increase provenance research on collections from colonial contexts and cooperations with countries of origin. Both framework principles and digitisation strategy were built on the "Guidelines on dealing with collections from colonial contexts" published by the German Museum Association (Guidelines, 2018; 2021). All these directives were the result of decades of appeals, claims and tireless efforts by researchers, activists and civil society groups on a global scale.

These official recommendations suggest that museums are to fulfil their historical responsibility related to colonialism primarily by gathering information on objects evidencing their colonial provenance and making this digitally available. It thus appears that digitisation of these holdings has not only become a governmental and national priority but has turned into a practical means for enacting ethical and political responsibility. In relation to large natural history collections, which commonly function as research museums, the moral imperative to digitise is further compounded by research on the climate crisis and biodiversity loss which requires ever more readily available information. Indeed, for the Museum für Naturkunde Berlin (Natural History Museum Berlin, MfN) this scientific urgency is one of the main drivers for collection development and digitisation.

While digitisation efforts in museums can expand access to collections, we want to caution against the hope that political problems can be solved by technical solutions. We argue that the digitisation of collections, like any other technology, integrates assumptions and preferences - about social groups, capacities, access, values - that, if left unchecked, shore up implicit biases and reproduce rather than redress historical injustices. In the following sections, we present different approaches and initiatives developed at the MfN and use them for asking critical questions about the assumptions and preferences congealed in digitisation efforts. Indeed, we argue that digitisation efforts provide an opportunity to engage with questions about historical responsibilities. Whose rationales and imaginaries govern digitisation? Who is served by normative concepts such as transparency, access, participation and standardisation? What types of access are pursued and for whom? What are the limits of participation in the digital and who are the beneficiaries of digitisation? We believe these questions can begin to account for the emerging social and political consequences of rapidly progressing collection digitisation.

The MfN provides an instructive case study for examining and reflecting on the digitisation of colonial objects in natural history collections. It holds a large collection containing specimens from all regions of the world that, for centuries, has formed a foundational source for scientific knowledge production. For decades, the MfN's specimen digitisation mainly served the exchange of information for fields such as taxonomy, morphology, biodiversity science, mineralogy and collection management. As a research museum, the focus has been, and remains, on making biodiversity information available to the scientific community. At the same time, the museum aims to establish an "open knowledge infrastructure" that will serve a variety of research questions relevant to society, educational purposes and other applications; sharing information about holdings from colonial contexts is one prominent priority (MfN, 2022a).

Like other national museums, the MfN ordered and facilitated extensive extractions from colonised territories. Colonial networks of officials, military and missionaries appropriated zoological, botanical and mineralogical materials as well as ethnological artefacts (Cisneros, *et al.*, 2022; Künkler, 2022). Museums accumulated and circulated materials and information about the colonies and profited from the asymmetrical, racialised structures of power and labour (Delbourgo, 2011; Heumann, *et al.*, 2018; Hicks, 2020; Hearth and Robbins, 2022). Expeditions led or endorsed by the MfN and other museums also pillaged burial sites and amassed human remains (Hicks, 2020; Künkler, 2022). Collecting institutions engaged in the (re-)production of colonial narratives - about white supremacy, "discoveries", racial typologies - in exhibitions and publications (Dijk and Legêne, 2011; Gelsthorpe, 2020). Natural history specimens formed the material basis for advancing colonial power and knowledge production, including scientific racism and eugenics (Kasibe, 2020; Nyhart, 2009, p.241 f.). Museums, as "knowledge-producing institutions", were the "administrative core of the empire" supplying information and expertise for controlling people and lands, the effects of which set in motion standards, practices and narratives that continue to this day (Richards, 1993).

The MfN collection includes mainly zoological and paleontological objects, minerals and rocks, animal sounds and associated archival material, like diaries, photographs, sketches, literature and notes (MfN, 2022b; c; d). It also holds human remains (MfN, 2022e; Decolonize Berlin, 2022). In 2018, the Federal and State Governments awarded the museum an extraordinary amount of funding for re-constructions and building developments, including the digitisation of its collection (MfN, 2022f). The combination of funding and MfN's history creates a unique institutional moment that allows us to observe and reflect on the digitisation process as it has been unfolding and explore the potential of interdisciplinary perspectives. During the past 10 years the MfN has developed into an integrated research museum, bringing together experts from natural sciences, information sciences, and uniquely, social sciences and the humanities. As co-authors of this paper who all work or worked at the MfN, our aim is to encourage debate and challenge our past and present scientific and institutional practices. Together, we wish to work towards an understanding of "historical responsibility" in relation to colonialism, which takes into consideration the specific history of the German Empire and its institutions, including museums, as well as the particular role of natural history.

In what follows, we open up a number of problem spaces which have emerged in the course of collection digitisation. We first use the museum's mass digitisation effort to address the tension between speed and specificity. We then move on to attending to the role of standards in the museum's "digitisation on demand" programme and the issue of specificity through discussing the term "colonial contexts". Subsequently, we draw our attention to the rhetorical mobilisation of what is termed as "communities of origin", often used to denote the beneficiaries as well as stakeholders of digitisation particularly in regard to colonial contexts. Arguing against the social imaginary that "communities of origin" implies, we propose to expand our political terminology to diverse publics as self-organised actors that can play a constructive and constitutive role in shaping digitisation processes that foster diversity, controversy and inclusion. We conclude this paper by illustrating possible futures for digital natural history collections.

The logic of digitisation

The digitisation of large numbers of objects at the MfN is already underway (MfN, 2022a; f). It aims to create an openly available digital collection catalogue containing: a) an agreed upon set of essential information that corresponds to requirements from national or international consortia; and b) partially standardised images that document the information available on the labels and objects. To increase the public visibility of this effort, an exhibition opened at the MfN in October 2021, titled "Digitize!" (MfN, 2022g). In addition to the presentation of countless insect drawers, the exhibition hall consists of an array of machines, assembly lines and computers. This “digitisation street” has been designed together with science and industry partners in order to capture digital images of 500,000 insects and their labels. The spectacle underscores a logic of digitisation driven by volume, efficiency and speed (Blagoderov, *et al.*, 2012; Heerlien, *et al.*, 2013). What are, we might ask, the costs of this logic? In other words, what gets lost when speed and efficiency rule?

These questions point to the “political stakes of mass digitization” (Thylstrup, 2020), which we are only beginning to fathom in the context of natural history collections. Concerning objects from colonial contexts, these stakes need to be considered in relation to a longer history of violent accumulation and its systematic erasure from institutional records. This history is not excised once these objects are reorganised in digital collections and global data infrastructures. On the contrary, ignoring the colonial origins of objects and bracketing off the enduring legacies of colonial violence and racism will ensure their perpetuation (Ashby and Machin, 2022). We face multiple challenges when attempting to account for these contexts. In most cases provenance of objects, i.e. the reconstruction and critical examination of their appropriation, translocation and presentation, has not been researched, remains partial or is unclear. Compounding the lack of knowledge is the fact that there is no default set of information (yet) that can identify and account for “colonial contexts” in the museum database and data portal. A pilot project at the MfN involving historians of science has tagged a selection of objects from the database using the categories “secured colonial context”, “probably colonial context” and “not verified” (MfN, 2022h). In addition, a decision tree that is currently in a trial phase will guide collection management staff to input object data to ascertain potential colonial provenance of the object. Also, developments are underway to expand the possibilities for keyword searches in the museum’s data portal. A content warning refers to culturally sensitive specimens as well as historical records. It promotes dialogue to discuss these holdings and correct or enrich metadata (MfN, 2022i). Furthermore, there is a focus on the type of language used, exploring substituting, for example, seemingly neutral terms in favour of words that more accurately reflect and specify the circumstances of appropriation (e.g. “loot”, “stolen” instead of the ubiquitous term “gift”).

While the intricacies of provenance research run up against the primacy of speed and efficiency, the volume and scaling of objects and data compels a flattening of diversity. Mass digitisation favours uniform collection types, such as insect drawers and herbarium sheets, but it also furthers a narrow, i.e. efficient, understanding of essential and relevant object data.

As such, digitisation of collections for biodiversity science may give rise to a new phase of what some call “information imperialism” that once again unilaterally extracts value and concentrates it in the dominant institutions in Europe and North America. More than 20 years ago, the science studies scholar Geoffrey Bowker warned that the database itself will ultimately shape the world in its image: “if we are only saving what we are counting, and if our counts are biassed in many different ways, then we are creating a new world in which those counts become more and more normalized” (Bowker 2001, p.675). The same is true for digitisation: By selecting what can and cannot be digitised and recorded, we actively shape our notions of nature and history and make them appear natural.

The digitisation of natural history specimens can therefore never be a neutral process: it always entails value-laden choices and selections, such as preferring speed and volume over considering how the historical context of objects might demand different, more responsible forms of processing. In the next section, we detail the domain of standards as one area of responsible processing.

Standards and their discontents

Digitisation is not a universal, standardised procedure despite its dependence on many types of technical and scientific standards. In fact, it is difficult to say what “digitisation” actually means and entails, aside from transforming physical objects into digital information. Besides producing a digital catalogue with basic information as described before, the MfN is also developing a user-driven approach to complement mass digitisation. The diagram “Digitization for everyone” below (Figure 1) offers a simplified overview of this digitisation on demand (Berger, *et al.*, 2021; MfN 2022f). We introduce this illustration as a point of departure to reflect workflows and assess the making and use of standards.

The procedure starts with a request for digitisation (1), by either internal or external users. Initially, the object inventories and databases are checked to see if required data are already available in digital form (2). In case the object or collection is not yet available in one existing internal collection database, the digitisation process starts by integrating any information describing the object

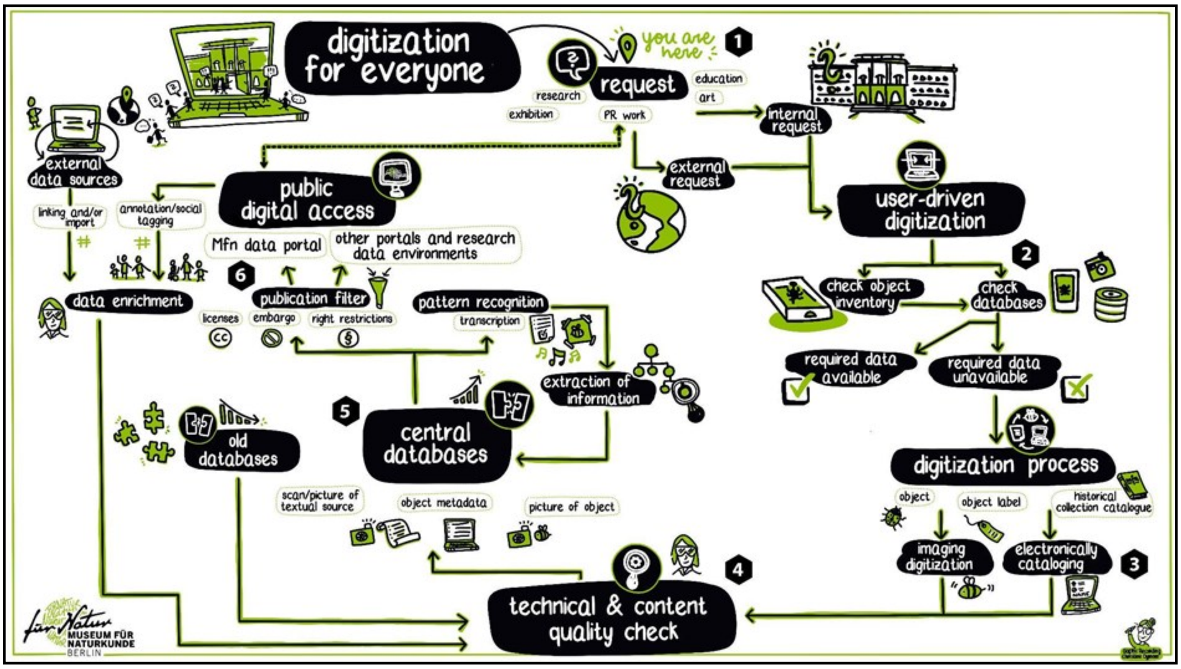

Figure 1. Digitization for everyone. Illustration of the digitisation workflow at the Museum für Naturkunde Berlin (modified after Berger et al. *2021,* *https://doi.org/10.7479/8h2v-4040).*

from historical, paper-based collection catalogues into a central database system (3). At the MfN, the collection database includes a stable identifier and an object title (e.g. the scientific name), other data, like collecting site, year and collector are usually also captured. In addition, digital images are taken of the object labels and, if requested, of the collection object itself (2- or partly 3-dimensional). Throughout the process, quality checks concerning technical aspects take place (4), guided by standards for image and metadata quality. In a next step, object-related information is integrated in the MfN's central database (5), where images, metadata and scans of labels or archival sources are stored and linked. Before being made publicly available in the MfN data portal (https://portal.museumfuernat urkunde.berlin/), the information passes through a publication filter (6). This step is designed to identify internally relevant data (e.g. shelf numbers), localities of endangered species or embargos (for results from ongoing research projects) as well as legal frameworks like general data protection regulations.

In addition to functioning as an internal orientation, this diagram reveals to users what digitisation entails while also suggesting a model for digitisation to other collection holding institutions. Its simplicity belies the complexity of digitisation, which mobilises actors and materials across and beyond the institution, thus requiring coordination work between institutional, technical, social and epistemic layers. This work depends on people making decisions throughout each of the digitisation steps listed above: decisions about the location of relevant data, the sufficiency of information, the appropriate depth of detail and the time spent on considering and researching connections to colonial contexts. Such decisions are often guided and abridged by the application of standards. The basis of the quality checks (4) are standards for format, data and metadata, as well as controlled vocabularies and processes (e.g. photographing specimens against white or black backgrounds). Standards are ubiquitous and powerful, they make digital objects cohere and mobile across different contexts, and they determine the users and uses of these objects. Indeed, many of the promises articulated in relation to digitization - from widening access to advancing knowledge discovery - depend on standardisation and interoperability, the ability for digitised objects and data to be searchable, discoverable, legible, sensible, exchangeable, citable and workable across different interfaces and domains (e.g. FAIR data principles: Findable, Accessible, Interoperable and Re-usable, 2016).

Yet standards, much like the objects and processes they govern, arise out of particular historical conditions. They are, as Bowker and Star argue, "artifacts embodying moral and aesthetic choices that in turn craft people's identities, aspirations, and dignity" (2002, p.4). In other words, standards represent value-judgements and they configure our world in certain ways. This is why efforts dedicated to redressing inequalities and biases in data and object collections have begun focussing on making new standards. The "CARE Principles for Indigenous Data Governance" (Collective Benefit, Authority to Control, Responsibility, and Ethics, https://www.gida-global.org/care), published in 2020, were developed by the International Indigenous Data Sovereignty Interest Group (within the Research Data Alliance) with the goal of ensuring equitable and just data practices and products that support the rights, interests and participation of Indigenous Peoples. The CARE principles guide the creation, use and reuse of Indigenous People's data, which includes data not only about Indigenous persons and collectives but also "about the environment, lands, skies, resources, and non-humans" (Carroll, S.; Garba, I.; Figueroa-Rodríguez, O.L.; *et al.*, 2020: 3). Current discussions on developing standards by which the provenance of Indigenous Peoples' data should be described and recorded bring together Indigenous Peoples, stakeholders from the Convention on Biological Diversity, the Nagoya Protocol and scientific publishers, among others. CARE principles are therefore relevant also for the digitisation of natural history collections given that specimens were removed from past and present Indigenous territories. Even if natural history materials may at first appear less problematic than cultural artefacts in ethnological collections, they and their data might have been appropriated in the very same circumstances such as wars or military campaigns. Furthermore, natural history collections are more than mere scientific objects or natural resources. Plants, animals, minerals or fossils were and still are integrated into cultural, economic and political contexts. Songs of the local population at Tendaguru (Tanzania), which originated during the excavation of dinosaur bones in the then colony of German East Africa, lament the loss of the culturally and economically valuable fossils, which were used as fertiliser or for medicinal purposes (Sadock, *et al.*, 2021). Therefore, natural history collections have good reasons for revisiting and reconsidering workflows and routines for identifying objects that require more sensitive handling and dialogue across institutions and diverse actors. More importantly, as natural history collections are central data infrastructures for biodiversity sciences and knowledge production, the development of novel standards needs to include questions concerning epistemic authority, i.e. the interpretation and definition of objects and concepts.

We suggest that digitisation of natural history specimens requires standards that are accountable to communities and publics which maintain historical and current (and future) relations with the objects and their former environment. Decision making should be rooted in collaboration that defines what collective benefit, control, responsibility and ethics might mean in relation to colonial natural history objects (Local Contexts, 2022; Enrich, 2022). In this respect, we argue for opening up the very process of developing standards, to design it as a cooperative process and to enable institutional and public learning (and unlearning) processes. Diverse project teams would combine different experiences, perspectives and claims in regard to the meanings and uses of collections. Here, as in other forms, digitisation can be thought of as multi-faceted, depending on the object, institution and imagination of the users. It is not an independent operation but deeply embedded in complex, ever changing institutional, organisational and socio-political dynamics and expectations (Hardisty, *et al.*, 2020).

"Colonial contexts": The specificities of historical encounters

Institution's identities were, and still are, defined by the modern paradigm that sees nature as utterly separate from culture (Latour, 1993). Subsequently, natural history collections continue to be regarded as unaffected by political, economic and cultural developments (Buchan, Forsyth and Gebreyohanes, 2021). This institutional paradigm is mirrored in the political and critical public debates on colonial collections where natural history objects play only a marginal role. However, natural history specimens are political and relational objects, connecting historical and current actors, techniques, and interests. They are the product of complex, often violent colonial formations (Ashby and Machin, 2022). As such they were shaped by social worlds and, in turn, have shaped these worlds including scientific networks and institutions, classificatory systems, collection economies, labour markets. One example from MfN being the aforementioned dinosaur bones from Tendaguru.

In Germany, policy documents and public discourse use the term "colonial contexts" to signal the socio-political colonial entanglements of museum collections (DMB, 2021, p.23). Discussions focus on "objects from colonial contexts", guidelines and recommendations are designed to ascertain "colonial contexts" (Framework Principles, 2019). The latter includes, for example, information on the geography and periods of formal colonial rule while also suggesting that museums look beyond such formal rule at asymmetrical power relations more generally.

The use of "colonial context" to label objects places emphasis on colonialism as a constitutive moment that extends beyond formal colonial rule. Yet, every "colonial context" is specific - in time and place - and characterised by specific constellations of actors, environments and socio-political conditions. Colonial rule was neither consistent, nor uniform. In fact, current research is dedicated to reconstructing and analysing colonial formations in particular settings and territories, such as medical experiments in German East Africa, the persecution of homosexuality in British India, and monetary policies in the French colonies in sub-Saharan Africa. In relation to natural history, scholarship is only beginning to understand the connection between, looting cultural goods in the course of genocidal campaigns in the German colony Southwest Africa/Namibia and animal trophy hunting by colonial officers in their spare time (Conrad, 2011). The specificities matter because different forms of colonial power have different political and ethical implications requiring appropriate responses in the form of, for example, restitutions, reparations, or other types of acknowledgement and redress. Differentiating and specifying colonial contexts also generates a knowledge resource for examining issues such as biodiversity loss and environmental destruction since their emergence and consequences are often tightly linked with imperial histories of exploitation.

What might this mean in relation to the digitisation of collection objects from "colonial contexts"? We suggest that processes of digitisation, such as the one described in more detail above (Fig. 1), involve the collation of information which can inform an assessment of the relations between colonial policies and postcolonial governance structures, including frameworks such as the Nagoya Protocol or the Global Biodiversity Framework. Such information - whether in collections or databases - is often messy: incomplete, unstructured or ambiguous. The instinctive response might be to clean this data, to trim seemingly irrelevant information or update historical terms, such as place names, for the sake of 'getting digitisation done'. While we do not want to dismiss the institutional pressures caused by funding guidelines, we suggest that the digitisation of collections should also be regarded as an ongoing enquiry into the history and future of collections. In this sense, it would be prudent to preserve the complexity of information.

Taking this into account, workflows need to accommodate pauses and interruptions for consultation and reflection. This would also necessitate the involvement of scholars from a wide range of disciplines engaging with colonial pasts and postcolonial presents (environmental history, global history, social and cultural anthropology, literary studies, political science) in digitisation processes. Concurrently, approaching digitisation as research entails consultation with and participation of publics that have stakes in and claims to the objects, their data and (historical) contexts of appropriation. And lastly, such re-framing would strengthen the recognition and status of personnel tasked with digitising.

Digitisation, as a form of enquiry, can highlight the kinds of connections made and, importantly, unmade between collections and colonialism. It demands specificity, also in how we digitise by, for example, developing different protocols (in relation to metadata, terminology, publishing etc.) for objects looted during so-called punitive expeditions or in the aftermaths of genocidal campaigns. In short, the digitisation process is not a mere transferring of analog to digital formats but could itself be seen as a form or method of research that can potentially recover the specificities of colonial encounters and thus contributes to a better understanding of the differential nature of colonial rule and its consequences. For the wider policy domain, which has—at least in Germany—settled on an unspecified evocation of "colonial context", such differentiated knowledge can inform responsible and appropriate political and ethical responses.

Digitisation for everyone? The question of inclusivity

The digitisation on demand outlined above is titled "digitization for everyone" (Figure 1). The evocation of "everyone" denotes the promise to be fully participatory: everyone should have access to the process and its products. Indeed, much of the literature on the digitisation of collections claims that it furthers "democratisation". This is a familiar promise in the context of technology development which should warrant critical scrutiny as should any easy conflation of technological innovation with social and political progress (Knöchelmann, 2021; Dutta, *et al.*, 2021). Therefore, we take a closer look at who is actually addressed in the digitisation of holdings from colonial contexts and discuss the potentials and possibilities of inclusivity in this process.

In European museums, a paradigm shift regarding the notion of accessibility and dialogue has recently taken place. For many decades, demands for restitution were met with a concerted, neocolonial and racist defence on the part of the overwhelming majority of decision-makers (Savoy, 2022). Due to activist, academic and political pressure this attitude appears to be changing, at least rhetorically: Public statements and policies now refer to cooperation, dialogue "on equal terms", transparency and, above all, relations with "communities". We encounter references to "source communities", "communities of origin" or "communities of interest" in both scientific and political debates concerning museum collections (DMB, 2021). These "communities" are also the main address of the CCC-Portal, the central digital repository for collections from colonial contexts in German public institutions (Collections from Colonial Contexts, 2021). Here, "community" is used from within institutions to designate external groups with historical, geographical, political or cultural affiliations to collection objects.

The ubiquity and ease by which "community" is evoked makes us pause and consider the work it does in institutional contexts, particularly when called up (or upon) by the institutions themselves. "Community" is a vague term but it suggests a communality, that is, shared values or visions. Community, as Raymond Williams noted, is "warmly persuasive" in "that unlike all other terms of social organisation (*state, nation, society,* etc.) it seems never to be used unfavourably, and never to be given any positive opposing or distinguishing term" (1983, p.40). The work it does is two-fold: on the side of the designated "source community" it projects a level of homogeneity that might not or that might no longer accurately reflect the present social organisation and political representation. This might complicate practices of restitution and reparation which are designed around national governments whose territorial boundaries might fall short of fully encompassing so-called source communities (who might also live in adjacent countries or in the diaspora). On the side of the institution, the mobilisation of "source community" enacts a division between "us" and "them". In this sense, the designation of community can shore up ideas of the racialised Other (Spivak, 1985; Minh-Ha, 1989), since "race often appears under the euphemism of community" (Ahmed, 2012, p.35). Therefore, when used by powerful institutions, the term "community" might at times prevent considering the full scope of democratic participation, continuing asymmetric power relations, while at the same time pretending a progressive agenda built on transparency, collaboration, self-determination, and restitution. In that regard, we propose to use collection digitisation, in all its different practices, to develop ideas of social organisation that go beyond the idea of pre-existing "communities" and nationally or culturally defined societies.

As repeatedly argued in recent scholarly debates, museums need to be transformed if they want to become forums for diverse publics (Omar, 2020). This includes their digitisation projects. Indeed, as the MfN's digitisation effort is gaining visibility and publicity, new kinds of collectives and discourses can emerge. For example, TheMuseumsLab, an exchange forum for museum professionals from Europe and Africa, discusses museum objects as a starting point for debates on global equality and justice (TheMuseumsLab, 2022). But it is also important to recognize that many initiatives and developments dedicated to realising participation and redressing colonial legacies are happening outside museums. Efforts here include the International Inventories Programme (2021), which is building a database for Kenyan objects held in institutions across the globe. The research project Mapping Philippine Material Culture (2022) does the same for artefacts from the Philippines. Both effectively deploy digitisation to create new translocal collections while also allowing new forms of public engagement. Such digital spaces of exchange can potentially open up opportunities for the emergence of new kinds of knowledge and the transformation of exclusive Eurocentric and institutional imaginations of museums within the public sphere.

The change towards digital collections and data infrastructures might sustain and extend dominant power structures, but it may also open opportunities for reconfiguring discourses, practices, and standards. Thereby, museums as custodians of global collections can take this as an opportunity, and responsibility, to open the process of authorship and ownership to different publics, even ones that we are not yet aware of. On a discursive level, we therefore suggest shifting away from the inherently selective formulation of "community" and instead focus on the variety of publics that may emerge around the contested matter of colonial holdings. Contested issues and matters of concern (Latour, 2008) may play an active political role in creating new conditions for political participation which is not bound by locality or nationality. In that regard, museums have a role in creating experimental spaces for public engagement and action to emerge, within and outside the institution, in digital and material realms.

Digitisation processes can make specimens public and visible as matters of concern and can bring diverse stakeholders and their respective - and many times agonistic - interests into the technological process (Müller, *et al.*, 2021). Therefore, we suggest striving for and building on this ability of digitisation to create these new kinds of forums to discuss and practise the transformation of collections in non-hierarchical, collective cooperation. On this basis, we aim for processes of re-working the data which are generated through research in the museum collection and charging them with historiographical, linguistic, systematic and taxonomic as well as logistical expertise from within and outside the museum.

Digitisation futures

In the previous paragraphs we highlighted some of the frictions emerging between the contemporary digitisation imperative and policy debates addressing the colonial contexts of museum collections. We argued that these frictions require theoretical, social and technological responses. The fact that natural history collections shaped and were shaped by colonial formations has been given little attention so far and has been thoroughly ignored in their scientific use. It is, therefore, crucial to acknowledge that digitisation processes are likely to duplicate the inequities and inaccessibility of collections, the reliance on Eurocentric concepts and standards and the effect of institutional as well as financial constraints. Institutional budget allocation also determines the expertise and experiences that are included or excluded in digitisation processes. Digitisation can easily continue the history of extracting knowledge and resources to enrich the institutional prowess and the accumulation of data. In fact, it is already impacting the discussion on physical restitutions of objects (DMB, 2021, p.87). Projects concerned with so-called "virtual restitution" are already taking shape (e.g. BOS, 2022; Reflora, 2022). However, these projects raise critical questions regarding their ability to facilitate accountability and negotiate various forms of digital and material restitution with diverse publics (Kaiser, 2022). Digitisation, we suggest, is an opportunity to investigate and redress past and present colonial formations while mobilising and including diverse publics in the institutional as well as socio-political transformation. It is a crucial point in time where we can stimulate an honest engagement with the material histories of collections and instigate new practices of science, accountability and restitution.

Digitisation strives to accomplish the monumental task of providing a synoptic view over millions of specimens in collections. Nonetheless, addressing colonial contexts with openness and accountability requires slowing down processes (Stengers, 2018), establishing collaborative and interdisciplinary methodologies for ongoing provenance research and enabling spaces for collaboratively developing other, more equitable standards. What is often omitted in political and institutional rationales is the fact that to generate big data and provide long-term storage capacities requires human expertise and an enormous amount of financial, technological, and natural resources; e.g. energy supply and the massive extraction of rare-earth elements (Poole, 2010). These aspects also create a divide, separating between those who have and those who haven't the economic and political power to digitise as well as store, maintain and own data.

Digitisation can offer an opportune starting point to address coloniality and global inequality in the distribution of knowledge resources as well as epistemic and ethical injustice. The reworking and reconceptualizing of digitisation processes requires long-term institutional transformation. This means opening the possibility of vulnerability and meaningful learning and unlearning processes.

While keeping careful attention to expected barriers and conflicts, we suggest a few directions that would ideally be at the core of digitisation processes oriented towards these political and institutional goals:

(i) Conceptualise digitisation as a global research field. This includes devising new forums to address and criticise the digitisation processes itself.

(ii) Establish international and interdisciplinary teams and stimulate the involvement of diverse publics from the very early stages of digitisation.

(iii) Invest time and resources in mediation processes and the training of staff.

(iv) Make digitisation open, iterative and correctable. Allow for a maximum of transparency of information sources, including the preservation of original designations, languages, contexts of acquisition and storage logistics.

(v) Ensure sustainability and accessibility of the data and the digitisation process itself.

(vi) Treat sensitive objects with care, follow existing recommendations and collaboratively defined ethical criteria.

(vii) Enable equitable cooperation, for example through exchange programmes.

We see digitisation as a critical and political process that would, and should, instigate controversies regarding the construction of data and context. This techno-social process may stimulate diverse publics that would take part and inform the discussion about the role of museums, the contested histories of collections as well as the very aim of digitisation itself. This is prerequisite for crafting digitisation as a new, dynamic and participatory museum methodology that potentially facilitates and challenges the core aspects of natural history scientific research - ordering, labelling, determining, comparing, defining, contextualising, debating - in an open and collaborative way, while allowing for epistemological and ontological pluralism.

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Hidden beauties: Using an orchid collection to provide an initial analysis of the Henry Leopold Foster Guermonprez Herbarium

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Abstract

In the early 1970's a large natural history collection from Bognor Regis Museum was transferred to Portsmouth Museums. Within it was a collection, estimated at between 60,000 – 80,000 specimens, mainly from West Sussex, amassed by Henry Leopold Foster Guermonprez. During his lifetime Guermonprez was well known in Bognor Regis where he lived but has since faded into relative obscurity, and aside from occasional references, his work remains under-recorded in the Sussex biological record. Accompanying the collection was a large archive of correspondence and over 3000 watercolours painted in the main by Guermonprez and his sister. A few of the watercolours are cited in 'Wild Orchids of Sussex' (Lang, 2001), although it appears that the herbarium specimens had not been consulted as several Guermonprez records for rarer species are missing. As one of the few areas of the collection to have been cited, Guermonprez's orchid specimens, watercolours and related correspondence were consulted to make a preliminary assessment of the quality of his botanical skills and knowledge to determine whether these could be applied across the herbarium.

Keywords: Guermonprez, West Sussex, orchid, herbarium, museum, Portsmouth, natural history

Guermonprez and his collection

Henry Leopold Foster Guermonprez (1858-1924) (Figure 1) was born on 5th July 1858, the eldest of two children of Jean Henri, a Belgian émigré and his English wife, Charlotte (Crane, 1974a). The family were originally based in Chelsea, but moved to Bognor Regis, West Sussex in 1891 following several vacations to the area. In 1892, following the death of Jean Henri, the family moved to Albert Road into a larger house called 'Dalkeith'. Henry married Clara Sophia Phelps in 1897 and the first of their four children was born the following year (Figure 2).

He appears to have been a self-taught naturalist, an interest shared by other members of his extended family. His cousin Amy Foster was a member of the Conchological Society and sent gastropods and bivalve molluscs back to Henry from her travels in the UK and abroad. Amy's specimens can be still found in Guermonprez's mollusc collection which is housed at Cumberland House Natural History Museum in Southsea, Portsmouth. Guermonprez's Aunt Harriet (Amy's mother) painted flowers and her work is thought to have had a stylistic influence on the early watercolours by Guermonprez and his sister Harriet (Crane, 1974b).

Figure 1. HLF Guermonprez in his study. ©Portsmouth Museums

Figure 2. The Guermonprez family in the garden of their home. ©Portsmouth Museums

Guermonprez trained and qualified as an architect, although there is very little evidence to suggest that he stayed within the profession, preferring to focus on Natural History and devoting much of his time building up an immense collection of plants and animals, mainly collected from West Sussex. His architectural background proved useful when drawing up plans for a private museum in the grounds of the family home to house the growing collection.

A neighbour and contemporary of Guermonprez's children recalled the layout and contents of the museum to which visitors and school children were welcomed. '*The birds, the eggs, the minerals to the right, the pile of flower drawings by the entrance, the fish, the crustacea……the butterflies and insects, and the visitor's book. I remember the wonderful assemblage, as if I had been there yesterday*' (Fleming, 1957).

Although Guermonprez published very few paper, he edited and contributed articles for 'The Selborne Notes', a weekly column in the West Sussex Gazette (WSG) from 1906 until his death in 1924. He had been persuaded to take on the column by the Editor of the newspaper, Mr Robinson, following the death of the previous contributor Rev Dr Arnold. Robinson noted in his letter as that Guermonprez had contributed to the column on several occasions he was satisfied that he was '*thoroughly well acquainted with the subjects of which the column treats*' (Robinson, 1906). Guermonprez's weekly column in 'The Selborne Notes' attracted attention and enquiries from members of the public, often enclosing a plant for identification. Some of these letters, with the plants attached, are still in the Guermonprez Herbarium.

Guermonprez's main contact with other natural historians appears to have been through correspondence, or welcoming visitors to his museum and home. He did not belong to many local clubs or societies and took little part in activities of the few societies that he did join.

Guermonprez appears to have walked to many collecting sites within Sussex and occasionally Hampshire, sometimes covering great distances. On one occasion he is known to have walked from Bognor Regis to just outside of Southampton hunting for crabs (Fleming, 1957). He is known to have left the house for days at a time, his granddaughter recalling '*I never heard that he travelled but would go on extensive walks from which he sometimes forgot to return home*!' (pers comms).

During the summer months, Guermonprez took his family in their two-horse chaise on field collecting expeditions to collect specimens, travelling as far as 18 miles from Bognor Regis to Graffham or Selham (Bognor Regis Post, 1957). The family is known to assisted with the collection in other ways. His son Jean *'smoothed the way the way to paternal approval by making some herbarium cabinets'* although having little interest in the collection himself, while his daughter Clara (1900-1961), known as 'Stella' painted some botanical watercolours (Crane, 1974b).

Guermonprez collected specimens belonging to most areas of natural history. Conservative estimates of the size of each area of the collection are in brackets below:

- Dry vertebrate material – uncased taxidermy, birds' eggs, birds' nests, and osteological material (c1300)
- Spirit collections (c100 jars, some with 30+ specimens in them)
- Vascular plants (c9000 sheets, many with multiple specimens)
- Marine algae (c1600)
- Bryophytes (c300)
- Fungi (c200)
- Lepidoptera (c13000)
- Coleoptera (c6000)
- Hymenoptera (c3000)
- Diptera (c6000)
- Hemiptera (c3000)
- Other insect orders – including Orthoptera, Odonata and Psocoptera (c1500)
- Mollusca (c4000 unit trays)
- Crustacea (c1400)
- Echinodermata (c150)
- Fossils (c1000 unit trays)
- Watercolours of specimens (c3000)
- Correspondence (c2000)

Following Guermonprez's death in 1924 the collection of 60,000 – 80,000 specimens remained in the family home until a bomb dropped in nearby Clarence Road in February 1943 (Getty, 1977) which shattered all the windows to the house and the glass of the display cases. Guermonprez's daughter and E.M. Venables, salvaged the collection, which mainly comprised plants, insects, crustaceans, molluscs, birds' eggs, taxidermy and fossils, relocating it to temporary accommodation at 'The Dome', a large late 18th century house in the vicinity. (Bognor Regis Urban District Council, 1959). In 1946 the collection was relocated to Lyon Street School where it remained until 1963. During this time the honorary curator, Venables focussed on the taxidermy specimens and little work appears to have been carried out on the remainder of the collection. (Getty, 1977). While at Lyon Street School the collection was exhibited at the local Methodist Church Hall in 1954 for a week which was sponsored by the Bognor Regis Urban District Council, followed by a second exhibition at St John's Hall, Sudley Road from 3rd to 10th July 1959. (Bognor Regis Urban District Council, 1959).

Recent work on the collection

Until 2018 work on the collection had taken place intermittently over several decades. The collections were held in crowded storage conditions making access to them difficult. Following the appointment in 2018 of a natural history curator to deliver the 'Wild about Portsmouth' funded by the National Lottery Heritage Fund, work to upgrade and increase collection storage areas has improved access. An overhaul of the database to create more structured records for the dissemination of data, and to improve access to them digitally is still ongoing. Due to its size and variety, there are still large areas of the Guermonprez Collection, that require cataloguing, data restructuring and rehousing.

Guermonprez's Herbarium

Guermonprez's herbarium, held at Portsmouth Museum and Art Gallery (PMAG), comprises approximately 9000 sheets of plants collected between 1880 and 1924 (Figure 3). As many of the sheets have multiple specimens, it has been estimated that there are between 40,000 - 50,000 individual plants (Getty, 1977). Some of these additional specimens are duplicates of the same species collected at the same time, others appear to have been added to the sheets at a later date when presumably Guermonprez ran out of herbarium paper.

The herbarium, which surpasses Guermonprez's other collections in the quantity of specimens and the volume of correspondence referring to plants, demonstrates his almost encyclopaedic knowledge in many areas of botany, providing a contemporary and detailed description of plant biodiversity in Surrey. However, there were botanical areas where Guermonprez was not so proficient as he sent many specimens sent to the Royal Botanic Gardens, Kew (RBGK) for identification.

With the pending demolition of the school, the Guermonprez and contents of Bognor Regis natural history collections were moved to temporary premises in The Manor House in Chichester Road, Bognor Regis in 1971 where they were assessed prior to the bulk of the

Figure 3. Herbarium specimen of Wild Madder (Rubia peregrina L..) at PMAG (PORMG : TN743/65) ©Portsmouth Museums

collections, including books, correspondence and paintings, being transferred to Portsmouth Museums between December 1972 and May 1974. Other areas of the collections were transferred to Littlehampton Museum (newspapers, drawings, horns, taxidermy heads), West Sussex Library (books), British Deer Society (taxidermy heads and horns), Chichester Museum (archaeology, paintings and mammoth tooth), Horniman Museum (exotic natural history), Weald & Downland Living Museum (agricultural implements) and Hitchen Museum (miscellaneous natural history).

Wolley-Dod (1937) in his introduction to the Flora of Sussex described Guermonprez as ‘a *botanist who should have been better known. His name appears in Salmon’s lists and in one or two entries in Arnold’s Flora’* and *‘He formed a first-class herbarium there, mostly from his own neighbourhood but embracing the whole county’* He went on to rank Guermonprez’s herbarium as one of three making up the west part of West Sussex (known as Division I).

The quality of Guermonprez’s preparation and mounting of plants suggests that he didn’t have as much time to spend on the collection as he would have liked, a point lamented by Wolley-Dod (1937): ‘*The specimens are well named and well preserved from insects, but many of them are not mounted and therefore not easy to consult, and liable to injury or misplacement of labels in going through them’.*

Unfortunately, the years between Guermonprez’s death and the collection being transferred to Portsmouth Museums realised Wolley-Dod’s concerns regarding misplacement of labels. There are over 100 labels which have become disassociated from their specimens, including two orchids, which are now presumed lost. The herbarium has been subject to insect attack in the past.

Aside from family members, Guermonprez does not appear to have worked in the field with other botanists and there is no evidence to suggest the contrary on the data labels of herbarium specimens consulted to date. The correspondence archive certainly indicates that he had been invited on botanical excursions on several occasions. Bernard Reynolds (dates unknown), whose herbarium also resides at PMAG wrote in March 1911 suggesting that Guermonprez accompany him and another botanist, Charles Edgar Salmon (1872-1930), on an excursion. ‘*I have lately succeeded in interesting Mr Salmon of Reigate (who as you are no doubt aware is one of our best authorities on British plants) in my list of Horsham plants and he has promised to take some excursions with me in the district. Would it not be good if you could come up for one the expeditions?*’ (Reynolds, 1911).

Guermonprez’s main collecting periods for plants (based on 3271 restructured records) appears to have been in the early 1890s and a more intense period between 1907 and 1914 (Figure 4). Guermonprez, his sister Harriet and his parents moved to Bognor Regis around 1891 which could explain a small flurry of plant collecting activity around this time. There may be vascular plants collected prior to this date as Guermonprez is known, from other specimens in his collections, to have collected insects from at least 1880.

Unsurprisingly, given that Guermonprez was based in the county, most plants in the herbarium were collected in West Sussex, followed by Surrey (Figure 5). Kent and Derbyshire are counties which regularly appear in records for other areas of the Guermonprez Collection. There may be a family connection living in these counties or simply places where the family went on vacation. The family is known from correspondence (Greenwell, 1914) to visit Buxton in Derbyshire for Mrs Guermonprez to visit the mineral baths for an unspecified medication condition.

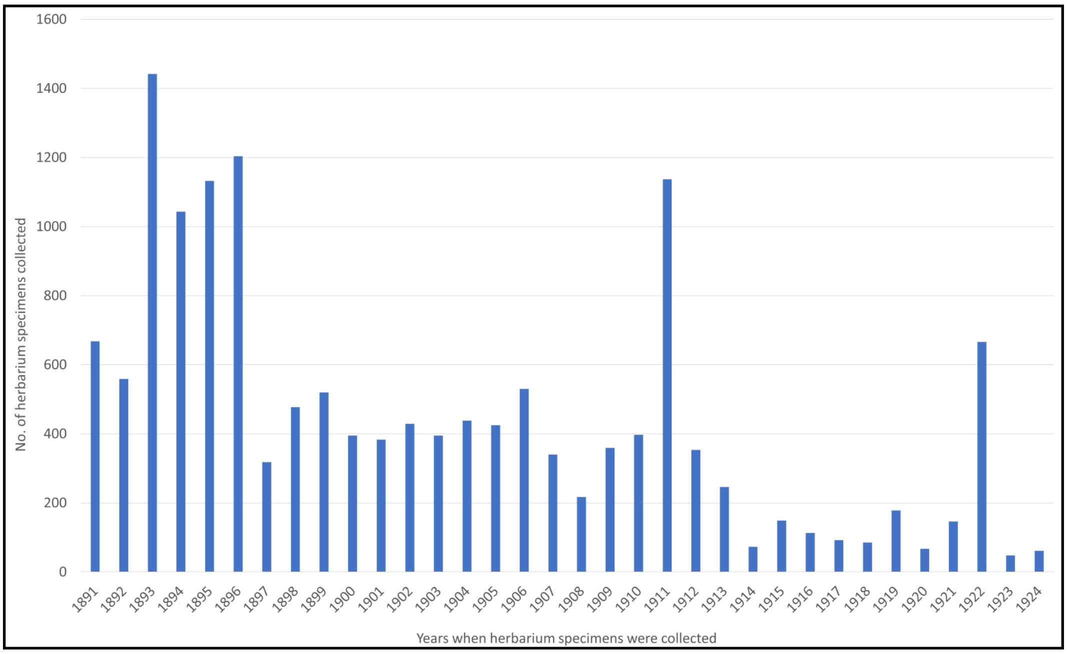

Figure 4. Number of plant specimens collected each year between 1891 - 1924.

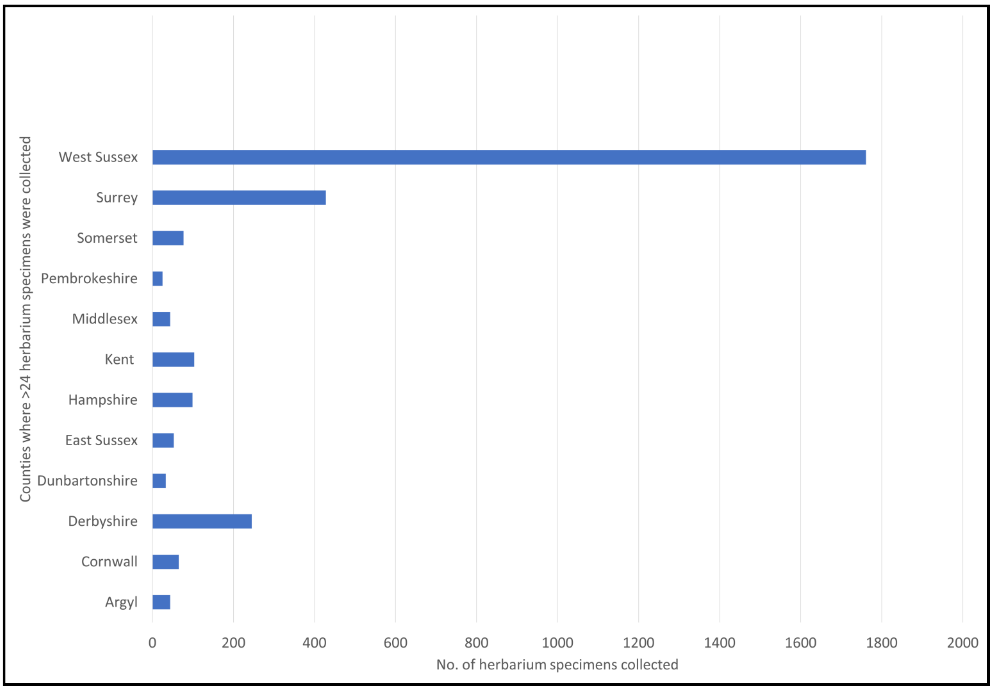

Figure 5. Counties where >24 plants were collected in the Guermonprez herbarium.

The herbarium has recently been the focus of two projects. In 2019 the entire Portsmouth herbarium, including Guermonprez's herbarium was rehoused into purpose-built herbarium cabinets. The plants were placed into colour coded genus folders to denote each collection and stored in taxonomic order. Rehousing has improved access to the herbarium, enabling targeted work to capture missing data and remount any loose specimens.

A project, 'Flora Explorer,' funded by the Headley Trust (2022-2024) has provided an assistant curator to work specifically on the Guermonprez Herbarium. The project has enabled focussed work on the herbarium by continuing work to improve the herbarium database and cataloguing plant specimens.

Figure 6. Herbarium specimens of Green-winged Orchid (Anacamptis morio (L.) R.M.Bateman, Pridgeon & M.W.Chase at PMAG (PORMG : Z/79/G/Hb-277) ©Portsmouth Museums

Guermonprez's orchid specimens

There are 284 orchid specimens in the Guermonprez herbarium, many collected by him, others were sent to him in the post knowing of his interest in the Orchidaceae family.

Guermonprez appears to have taken more of a pride in his orchid collection compared to other areas of his herbarium, many specimens are well mounted, by his standards and often with additional provenance data (Figure 6). One detail, not seen to date on other herbarium sheets, is the inclusion of hand drawn sketch maps (Figure 7) on several orchid data labels which illustrate the exact location of where the plant was found.

With the exception of a few 'hot house' examples and specimens from Europe, the orchids specimens were collected from 21 vice-counties in Great Britain. Vice-counties (often abbreviated to VC) were a fixed geographical boundary defined in the mid-19th century still used in biological recording. Table 1 provides a list of orchid species in the Guermonprez Herbarium and indicates the vice-counties where they were collected.

Nearly 70% of orchids were collected from two counties with 149 (52%) from West Sussex and 59 (over 20%) from Surrey Derbyshire and Kent (7 specimens from each) have already been identified as places frequented by the family on a regular basis. Orchid specimens from Scotland are of species that do not occur in southern England and appear to be from the collection of Harold Warren Monington (1867-1924), a botanist with whom Guermonprez corresponded with

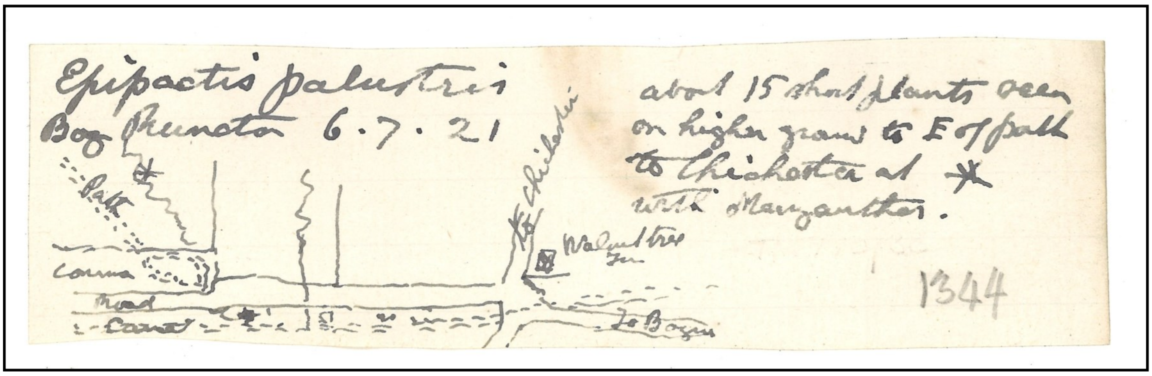

Figure 7. Detail of a label with a sketch map of the location that the plant was found. ©Portsmouth Museums

*Table 1. Orchid species and their vice-county (VC) in the Guermonprez Herbarium. *Indicates the existence of a label of a second specimen which has subsequently been lost.*

Genus / Species	No. from West Sussex VC 13	No. from Surrey VC 17	Other VCs in the orchid collection
Cephalanthera damasonium (Mill.) Druce	10	7	-
Cephalanthera longifolia (L.) Fritsch	12	-	-
Epipactis palustris (L.) Crantz	4	-	-
Epipactis atrorubens (Hoffm.) Besser	-	-	VC 7/8
Epipactis helleborine (L.) Crantz	20	4	VCs 24 & 49
Epipactis Zinn	-	-	VCs 7/8 & 57
Neottia ovata (L.) Bluff & Fingerh.	8	12	VC 57
Neottia nidus-avis (L.) Rich.	10	3	-
Goodyera repens (L.) R. Br.	-	-	VC 96
Hammarbya paludosa (L.) Kuntze	-	-	VC 96
Coeloglossum viride (L.) Hartm.	10	-	VC 57
Herminium monorchis (L.) R. Br.	8	-	-
Gymnadenia conopsea (L.) R. Br.	4	3	-
Spiranthes spiralis (L.) Chevall.	7	-	VCs 6, 11,14 & 49
Platanthera chlorantha (Custer) Rchb.	6	-	-
Platanthera bifolia (L.) Rich.	9	3	VC 70
Ophrys apifera Huds.	4	2	VCs 6, 16
Ophrys insectifera L.	6	4	VC 11
Himantoglossum hircinum (L.) Spreng.	1*	-	-
Neotinea ustulata (L.) R.M.Bateman, Pridgeon & M.W.Chase	-	1	-
Orchis mascula (L.) L.	2	2	VCs 7/8, 15, 66
?Dactylorhiza maculata subsp. ericetorum (E.F. Linton) P.F. Hunt & Summerh.	-	-	VC 98
Dactylorhiza maculata (L.) Soó	6	9	VCs 57, 70, 98
Dactylorhiza incarnata (L.) Soó	8	1	VCs 1, 10
Anacamptis morio (L.) R.M.Bateman, Pridgeon & M.W.Chase	5	3	VC 15
Anacamptis pyramidalis (L.) Rich.	7	2	-

occasionally. Data from other areas of the Guermonprez Collection indicates that he visited Scotland on several occasions, but not in pursuit of orchids.

There are proportionally more orchids from Wiltshire (2% or 6 plants) when compared with the remainder of the herbarium (0.5%). These were collected by Krumholz who was based in Surrey and contributed plant specimens from other families to the herbarium (Figure 8).

Guermonprez's orchid collecting activities in West Sussex appear to have mainly focussed on the west of the county (Figure 9). He may have been influenced by Rev. Frederick Henry Arnold (1831 - 1906) who was renowned for collecting from the same part of the county. Arnold's 'Flora of

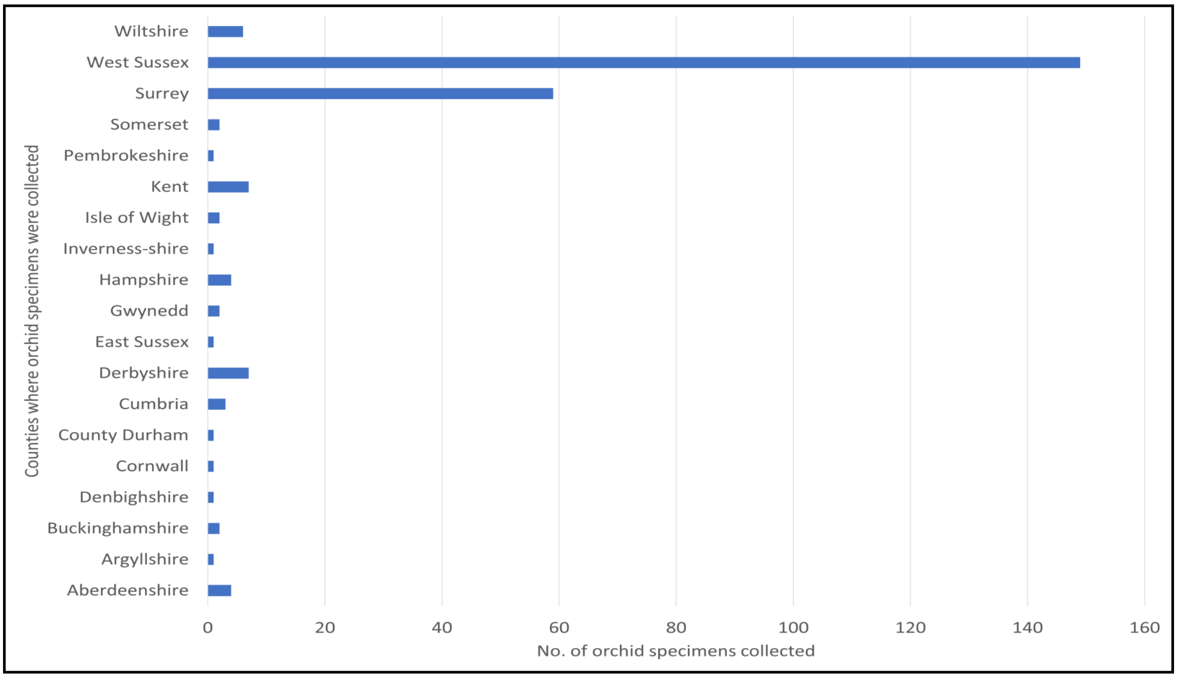

Figure 8. Showing counties where orchids were collected.

Sussex' (1887, revised 1907) was a starting point for many botanists at the end of the 19th century / beginning of the 20th century and is frequently referred to in the correspondence archive, often as a prelude to an enquiry to Guermonprez regarding an identification to a plant.

Of the 29 species of orchids listed in Arnold (1907) Guermonprez indicated that he had found 20 and underlined the localities of where he had found them or where he was informed of a record.

Guermonprez's annotations appear to be a compilation of notes from correspondence and his own observations from specimens in his herbarium or through watercolour paintings. In some instances, he added localities of plants not listed in the 'Flora of Sussex'. Other annotated details include sketches of flowers, collector / recorder and numbers of plants seen.

The most frequently visited orchid localities in West Sussex were Goodwood and Lavant, both

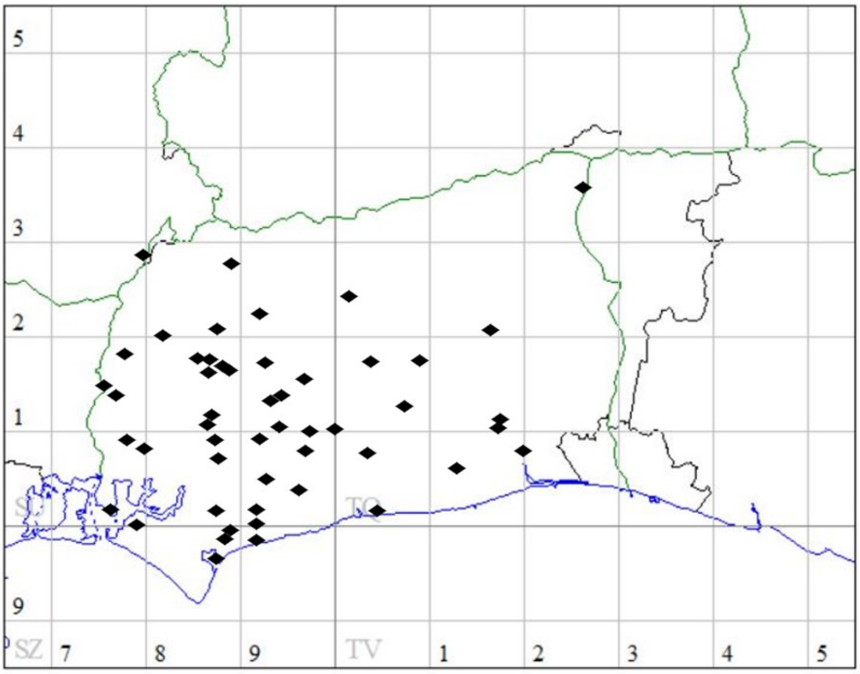

Figure 9. Map of West Sussex and bordering counties with orchid species locations plotted.

both approximately 10 miles from Bognor Regis. The greatest distance travelled by Guermonprez for an orchid was 45.2 miles to Seaford, East Sussex on the 22nd August 1910 where he collected an Autumn Lady's-tresses Orchid (*Spiranthes spiralis (L.) Chevall.)*.

There appears to have been an initial burst of collecting activity in the early 1890s, shortly after the Guermonprez family moved to Bognor Regis, followed by the most productive year for the collection of orchids, with 25 specimens representing 10 species collected in 1893. The years 1907 and 1914 were also productive collecting periods for Guermonprez, with a peak of collecting activity during 1911 and 12 orchid species collected that year. A final plant and orchid collecting flourish took place during 1921. (Figure 8) The collecting spikes in Guermonprez's orchid records mirror dates on other plant records in his herbarium.

Guermonprez's watercolours

The Guermonprez collection of watercolours comprises some 3,000 natural history images, mainly of plants, painted in the main by Guermonprez and his sister Harriet, with a few by their aunt, Harriet Foster (1891 -1903). Crane (1974b) suggested that Harriet Foster had a stylistic influence on her nephew and niece, although he dismisses her watercolours as of '*no botanical and little or no aesthetic note*'.

The watercolours provide an indication of scale or are painted at life size and are annotated with notes and illustrations of key features including petal shapes and key features (Figure 10). They also capture the plant subjects in a more life-like pose than herbarium specimens which have often faded. Guermonprez's annotations on some of the paintings also state how close the colours used compare to the living plant.

There are 51 watercolours of orchids which are thought to have been painted after collecting given the detail of the watercolours and the quantity of plants collected on some excursions. A Bird's-nest Orchid sent in the post to Guermonprez in 1913 to identify by Mrs Pocock from Surrey, subsequently illustrated and added to the herbarium, has a note (possibly by another member of the family) '*I have put it safe in your vase to keep it for you*' (Pocock, 1913).

Twenty-four watercolours are of orchid specimens in the herbarium, many providing more precise localities and dates than the plant specimens. Fourteen watercolours may represent specimens

Figure 10. Watercolour of herbarium specimen of Narrow-leaved Helleborine (Cephalanthera longifolia (L.) Fritsch) at PMAG (PORMG:2014/1/7) ©Portsmouth Museums

that were unsuitable for mounting or have since been lost as the plants are not in the herbarium.

One of the watercolours depicts a rarer orchid, the Lizard Orchid, Himantoglossum hircinum (L.) Spreng., found by H Tyler at Steyning, and given to Guermonprez on 25th June 1911. This painting appears to have been overlooked by Lang, although a later painting from Halnaker in 1924 by Miss Joop is referenced. Sadly, this latter specimen has been lost, although the original label survives which shows that it was collected from a chalk pit at the base of Halnaker Hill on 23rd June 1924 when it was first painted. A second illustration of the plant on the same sheet is dated just over a week later on 2 July shows the flowers more fully opened. (Figure 11)

During his research for 'Wild Orchids of Sussex' Lang (2012) appears to have focussed on watercolours to capture data rather than Guermonprez's herbarium sheets and correspondence, presumably because the latter two were unavailable or not easily accessible at the time of research.

Work on the Guermonprez Herbarium to match up illustrations with the database, linking watercolours with their specimens is planned for 2023/2024 as a volunteer project.

Figure 11. Watercolour of missing herbarium specimen of Lizard Orchid (Himantoglossum hircinum (L.) Spreng.) at PMAG (PORMG:2014/1/13) ©Portsmouth Museums

Guermonprez's Correspondence

Guermonprez appears to have been a prolific writer spending an inordinate amount of time replying to correspondence. There are over 2000 letters in the archive, with many correspondents acknowledging Guermonprez's kindness and patience in answering their enquiry and generosity with sharing his data, even with casual correspondents.

Many letters were written in response to the weekly column 'The Selborne Notes' in the WSG which published Guermonprez's address. Other correspondents shared Guermonprez's passion for natural history, possibly having met him while collecting or by reputation, often exchanging specimens and data with him. Letters appear to have been answered within one or two days of receiving them, certainly within a week as the top left-hand corner of many letters is annotated with *ans* [answered] with a date along with Guermonprez's identification of a specimen(s).

The column also generated interest from biologists working in the field, including Charles Baynard Tahourdin, (1872-1942) who wrote following an article Guermonprez had written about orchids and was looking for a specimen of *Epipactis palustris (L.) Crantz*., Tahourdin, whose herbarium is housed at Reading University, was in the process of painting orchids for his forthcoming book.

Other correspondents identified to date include botanists CE Salmon, BR Reynolds, FH Arnold, Anthony Hurt Wolley-Dod (1861 -1948) and HW Monington. All of them appear to have accepted Guermonprez's credentials as botanical orchid authority.

Further plant related correspondence, which provides anecdotal references to species will be analysed and transcribed to identify further areas of Guermonprez's botanical expertise and possibly areas where he was not so proficient.

Discussion

Guermonprez's orchid specimens provide good anecdotal evidence of where and when the plants were collected. Although grid references were not in use at the time of collection, the herbarium sheets nevertheless provide an accurate locality (occasionally with a hand drawn map), with a date and often with habitat data or an indication of numbers present. Hand drawn maps have not been found on specimens in other areas of the herbarium to date, these may, if located, provide an indication of the importance of a specimen to Guermonprez.

Herbarium specimens ensure that any incorrectly identified or indetermined specimens can be re-examined and reassessed if a record is in doubt. Wolley-Dod (1937) notes in his introduction to the Lesser Butterfly-Orchid, Platanthera bifolia (L.) Rich.: '*Some records may belong to the next species* [Greater Butterfly-Orchid], *since the early botanists, and some of the recent ones, do not distinguish it'*.

As Wolley-Dod had access to Guermonprez's herbarium following the latter's death, (Wolley-Dod, 1939) it may be assumed that the identities of these were correctly recorded at the time.

Historic herbarium specimens were not always prepared and pressed to highlight diagnostic characteristics or may have been collected before a plant had fully flowered making identification very difficult to check easily. This is certainly true of some of Guermonprez's orchid specimens and of other plants in the herbarium.

Fortunately, the watercolours provide a secondary identification resource as Guermonprez and his sister often included detailed close-ups of parts of the plant with annotations. These were checked by local members of the Hardy Orchid Society in 2022 and, aside from a few which were not to the same standard as the other examples, (possibly the work of Guermonprez's Aunt Harriet?) deemed to be good representations of the living plants.

Can Guermonprez's and Harriet's watercolours of orchids be taken at face value and used as a biological record? Lang (2001) certainly had no issue accepting them. Some watercolours provide evidence of specimens that no longer exist. There are over 100 disassociated plant labels in the archive and there may be further examples of watercolours in the archive relating to some of these lost herbarium specimens.

However, relying on the watercolours for identification cannot be applied across the whole herbarium. In September 1913 Guermonprez deposited an unspecified number of drawings at the Royal Botanic Gardens, Kew for identification. They were returned the following week commenting that while some identifications could be suggested, the drawings were '*not sufficiently detailed to admit of further determination*' (Kew, 1913).

The correspondence from Tahourdin, Reynolds and other botanists clearly accept Guermonprez's competency with the Orchid family. Working through the rest of herbarium and correspondence may identify further botanists associated with the collection as well as other areas of his botanical expertise or gaps in his knowledge.

Data on Guermonprez's orchid specimens demonstrates that many of the plants collected in West Sussex were from the west side of the county. This may be a result of more habitats suitable for orchids in these areas or a bias caused by basing collecting activity on Arnold's sites listed in his 'Flora of Sussex'. Many sites from where orchids were collected reflect those represented in the herbarium identified to date, apart from the paucity of orchid specimens from Bognor Regis.

Over 900 plant specimens from Bognor Regis have been identified in the herbarium to date, and the town is also heavily represented in other areas of the collection. Habitat therefore needs to be considered when making comparisons with other areas of the collection. There may be other sites that have been overlooked which could come to light as work on the herbarium progresses.

The specimens of Marsh Helleborine, *Epipactis palustris* (L.) Crantz, provide evidence of habitat loss as most of the historic sites where the plants were recorded have now been drained, resulting in a sharp decline of the plant in Sussex. Further work on the Guermonprez Herbarium and other areas of the Guermonprez Collection may provide additional evidence of habitat loss or environmental change.

Two copies of Arnold's Flora of Sussex (1097), previously owned by Guermonprez, were recently donated to Portsmouth Museums in 2022 along with a transcription by Francis Abraham (1995) of Guermonprez's annotated notes written in the margins. These currently provide an indication of the contents of the herbarium until it can be fully catalogued.

Conclusion

The orchid collection has proved an excellent focal point in which to begin an analysis of the Guermonprez Herbarium. Focussing on a smaller dataset has indicated a tentative collecting range of dates and sites for the not just the remainder of the herbarium but potentially for the remainder of the collection. With its life-like illustrations and magnified details of parts of plants, as well as provenance data, the watercolour collection provide an additional layer across the herbarium. Work is still required to determine whether the watercolours represent all of the plant families collected by Guermonprez. The correspondence archive provides evidence of Guermonprez's attention to detail and expertise, from answering plant enquiries to consulting with experts in the field, indicating where the strengths and weaknesses of Guermonprez's botanical expertise might lie.

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Curious specimens in the collection: Comparative dental anatomy, skulls, and historical catalogues

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Abstract

In the Museum of Life Sciences at King's College London is a series of craniofacial specimens which were originally housed in the Royal Dental Hospital of London and the London School of Dental Surgery. These sagittally-sectioned skulls and mandibles are distinctive in their preparation. One half skull and mandible have been dissected out to show the roots of each tooth. This made these specimens particularly useful for teaching dental students about different dentitions, which was a required part of the curriculum for becoming a dental surgeon. However, the sectioned component parts had become separated over the decades, and we searched the collection with the intention of reuniting these parts into a complete specimen. Using historical documents from the Royal Dental Hospital and the London School of Dental Surgery, we traced specimens through their early histories, matching specimens with their identifications, catalogue entries, and donors. A selection was then mounted and labelled for preservation as part of a trial to develop a system for handling these delicate specimens.

Keywords: Royal Dental Hospital of London, Odontological Society of Great Britain, handling collection, Museum of Life Sciences, KCL, dentistry, education, history of dental surgery

Introduction

Over the last few years, the Museum of Life Sciences at King's College London has been documenting specimens from a comparative odontological collection that originally came from the Royal Dental Hospital and London School of Dental Surgery. Many of these specimens can be dated to the early 1900s. It became apparent that what often appeared to be numerous loose bone fragments kept in several open storage boxes were, in fact, a group of sagittally bisected (cut through the midline) skulls. These skulls represented the various dentition types of the several different functional feeding groups (carnivore, omnivore, insectivore, etc.).

The specimens comprise whole mammalian skulls and mandibles and skulls sectioned for mounting into quadrants, two quadrants of which are dissected to show the roots of teeth on one side. They were used to demonstrate vertebrate tooth morphology to dental students, but over time the skull components became separated. Decades later some were found, rerecorded, and boxed separately. Because the various parts were not seen together, and consequently were not identified as parts of a single specimen nor parts of a collection, the significance of skull/mandible/four quadrants was not recognised. As a consequence, the individual parts were considered to be of little value.

A project funded by the Bill Pettit Memorial Award, awarded through the Natural Sciences Collections Association (NatSCA), was undertaken to document and preserve this group of delicate specimens, establishing that at least some of the specimens in the craniofacial collection are of historical importance in the development of dental education and research into comparative odontology. Many have now been restored, re-mounted, and re-labelled to show the quadrants as they would have been displayed originally. This article features some of the specimens that have been examined and the processes of identifying and restoring them.

History of the craniofacial collection

The Odontological Society of London (est. 1856) was created with a two-fold purpose: to provide a forum for dental practitioners to exchange ideas and techniques and to provide a corporate body to raise professional standards by implementing an examination for dental surgery (Payne, 1925). Legislation, which required a mandatory professional qualification (L.D.S., Licence in Dental Surgery) in order to practise as a dental surgeon, introduced some degree of regulation to the profession (Gelbier, 2017). Consequently, it was necessary to have a suitable institution where training and examination to meet these new requirements could be fulfilled. In 1858, the Odontological Society founded the Dental Hospital of London (later the Royal Dental Hospital, RDH). In the following year, the London School of Dental Surgery (LSDS) was established in the Hospital to instruct dental students on a course meeting the requirements of the L.D.S. (Smith and Cottell, 1997; Gelbier, 2017). This included an element of comparative dental anatomy which involved the work of Charles Sissmore Tomes (1846-1928).

Charles Tomes was a dental surgeon who specialised in craniofacial anatomy, expanding on the work of his father (Tomes and Tomes, 1873). Trained in both Natural Sciences and Medicine, he had an interest in comparative anatomy and was an authority on odontology, tooth morphology, and dental histology. His work, *A Manual of Dental Anatomy, Human and Comparative*, first published in 1876, became an important reference book for understanding differences between the dentitions of a wide variety of animals. During preparation of this book, Tomes accumulated a number of specimens and these, together with some of his father's work and with specimens discussed at evening meetings of the Odontological Society, formed the 'Odontological Society Museum', established in 1859. This museum included whole skeletons, though the craniofacial portion consisted of whole skulls, mandibles, teeth, and sectioned specimens of these parts.

In 1872, impelled by a large consignment of specimens received from Australia and an impending move to new premises in Leicester Square, Charles Tomes catalogued the collection. In his first survey of the contents of the museum, Tomes produced a comprehensive listing of specimens, and this catalogue was published in the *Transactions of the Odontological Society* (The Odontological Society of Great Britain, 1874). The LSDS selected specimens from this catalogue in order to teach the comparative dental anatomy part of the curriculum for the L.D.S. (Smith and Cottell, 1997). The collection continued to expand, and there were two further catalogues assembled in 1885 and 1894. The 165-year-old record is incomplete and confused, so it is not possible to entirely reconstruct the collection completely. The bulk of the Odontological Society Museum passed to the Royal College of Surgeons of England in 1909, leaving the remainder at the LSDS where it continued to be used for the Comparative Dental Anatomy course until the 1970s (Gelbier *et al*., 2021).

Documents at the Museum of Life Sciences relate to the Comparative Dental Anatomy collection which was retained at the LSDS; one is a taxonomic catalogue of osteological specimens produced by Tomes (the 'Special Catalogue'). The second is a series of 90 practical sheets, produced after 1874, which relate to specimens listed in the Special Catalogue. A third document, the 'List of Donors and Donations', indicates that members of the Odontological Society continued to donate specimens to the LSDS collection after 1901, rather later than the published catalogue suggests.

There have been inevitable losses of specimens but also additions by successive generations, each of which has introduced their own particular, cumulative anomalies to the collection and its documentation. Whilst the original record-keeping was adequate, this has not always been the case, particularly in more recent decades when the collection was largely unmanaged. As a consequence, the exact inventory of the original collection is unknown. The collection was also moved twice and has been merged with another partially documented collection of zoology specimens, when United Medical and Dental Schools and King's College, London merged in 1998.

Where the records are more complete and the specimens can be found, the group can be reassembled as a collection. As part of this process, a small group of sectioned and dissected skulls of mammals has been located and reassembled. Each skull has been sagittally bisected resulting in four parts: two skull/maxillary sections and two mandibles (see Figure 1). The teeth of the left-hand side have been exposed by removal of the alveolar plate, exposing the roots for inspection as described by Charles Tomes (Tomes, 1882). This makes the collection of particular interest in the history of dental surgery, comparative dental anatomy, and education in these fields.

Identifying specimens was contingent on locating each of the component parts which had often been previously catalogued and boxed as separate specimens. Initially, a simple visual match could be made, for size and for other physical attributes, such as colour, texture, staining, etc. It was necessary to identify and reunite mandibular and maxillary quadrants and confirm a match by checking the occlusal fit of the upper and lower tooth arcade which is unique to each pair because of local wear. Sometimes the animal could be identified using old labels (when present), but otherwise they were identified by matching unlabelled specimens against historical records if possible. Where records were missing, more recent reference materials were consulted to aid identification of specimens.

Early days

Early in the project, two large fragments of a sectioned skull comprising a right-hand part-cranium and maxilla complete with a full set of molars, and a second fragment comprising the right -hand premaxilla (Figure 1a), were found in a box of bone fragments. Identification was hampered because they were unlabelled, and a large proportion of the skull had been damaged or removed during preparation.

The general appearance and arrangement of the incisors indicated a large rodent about the size of a beaver (see Table 1 for the naming conventions for teeth used in this paper). However, the incisors were smaller, less robust, and pale in colour rather than the orange, iron-stained enamel front surface of a beaver (Beddard, 1902). Fortunately, all the molars were present and in good condition, so it was possible to identify the reconfigured skull. Tooth morphology of the molars indicated the family Caviidae (Verzi and Quintana, 2005; Berkovitz and Shellis, 2018), and the skull size and shape, which was too large for a guinea pig but too small for Capybara, indicated the genus *Dolichotis* Desmarest, 1820, the mara (Owen, 1845) (Figure 1a). Because it was in quite poor condition and was only a partial skull, the specimen was put aside for further appraisal later.

More recently, a 150mm cork-lidded glass tube was found amongst other specimens in the collection. The label, 10.19.5, combined with existing documents identified it as *Dolichotis* (Figure 1b, c). Because this tube potentially contained another part of the skull, it was re-assembled. Unfortunately, the tube contained only fragments: an upper and lower left incisor, left mandible (dissected), a condylar process, two fragments of the right mandibular molars, and three left maxillary molars (Figure 1c). There were no other bone fragments, suggesting that the left skull quadrant has been lost.

Figure 1. Parts of a skull found in the collection. 1a: Sagittal section of Dolichotis *skull, 1b: a specimen tube from the collection, 10.19.5,* Dolichotis, *1c: Tube contents sorted into quadrants.*

Table 1. The naming conventions used for teeth in this paper.

Maxillary tooth	I: incisor, C: canine, P: premolar, M: molar + superscript *e.g.,* M^1
Mandibular tooth	i: incisor, c: canine, p: premolar, m: molar + subscript *e.g.,* m_1

According to Owen (1845), the tooth formula for a *Dolichotis* is:

$$\frac{1.0.1.3}{1.0.1.3}$$

This formula appears consistent with what remains of the specimen. Because only the tube contents were labelled, it will never be possible to confirm with absolute certainty that this was a single prepared specimen, although only one skull was listed in our records. The form of the dissection is consistent with others in the collection, and all the parts match in size. It does not seem unreasonable to suggest that these two specimens could belong together, so the parts have been catalogued together.

A Mystery specimen revealed

There was no label present in another glass tube which contained a mix of loose teeth and fragile bone fragments. Obscured amongst the tightly packed teeth, a bone appeared to be part of a skull. Carefully pouring the contents into a petri dish revealed four quadrants - two half-mandibles and what looked like two paper-thin skull sections. No teeth were in position in the dissected side, hampering recognition. However, the presence of a whole skull, or rather all four quadrants, was indicated by the appearance of two of the bone fragments, each of which had a section cut away to show the roots of the teeth. It seemed to be a whole upper and lower right and a dissected upper and lower left skull pair (Figure 2). This quadrant convention for comparative dental specimens is an emerging theme in the collection. Unfortunately, because many specimens have become dispersed or lost, it is not always apparent if all the quadrants can be located.

The whole right-hand mandible, (left in Figure 2) was complete, but the right-hand skull section was missing two incisors, the rear-most molar and one other intermediate tooth in the maxilla. The left-hand skull section (right in Figure 2) was unrecognisable given the lack of order and context in the dish, the absence of teeth, and the fact that the sections are only part skulls. They were difficult to comprehend as complementary elements of a single skull until they were each oriented correctly, as shown below in Figure 2. This difficulty is illustrated in the previous *Dolichotis* specimen (Figure 1b).

The mandible was typically diprotodont with a large procumbent incisor, and the 1-premolar + 4-molar arrangement of the posterior teeth was typical of marsupial dentitions such as those of opossum, cuscus, kangaroo, and wallaby (Tomes, 1923). The upper anterior dental arcade, with three strongly curved incisors followed by two widely spaced unicuspid teeth (C and P^1; see Table 1), is typical for the koala and for the Phalangeridae group of opossums and cuscuses.

Figure 2. The skull of Trichosurus vulpecula *(Kerr, 1792) arranged into quadrants before restoration.*

The general tooth formula for the Phalangeridae (Berkovitz and Shellis, 2018), is:

$$\frac{3.1.2.4}{2.0.1.4}$$

which matches our specimen. Comparison between this skull section and other skulls in our collection resulted in a close match to *Trichosurus vulpecula* (Kerr, 1792), the common brushtail opossum. After comparing the tooth formula and some skull reference images, sorting the teeth in a petri dish showed that most, if not all, of the teeth were present and so they were divided into approximate upper and lower sets (Figure 3a, 3b). The maxillary incisors (I^{1-3}) formed a simple anterior triplet and were identified first. Their unique curved form and respective sizes made selection straightforward. These teeth, particularly I^2 and I^3, were worn into an arc at the cutting surface at the point at which they occlude with the lower incisor i_1 (Figure 4). Starting with the right-hand whole maxilla, each tooth was secured in position with buffered PVA glue, but drying time gave plenty of opportunity to make small final adjustments to achieve perfect alignment. The finished quadrants were then set aside to cure.

The intermaxillary suture on the skull was clearly defined, which facilitated placement of the canine as the first tooth in the maxillary arcade. This was followed by the slightly confusing caniniform first premolar which has almost identical morphology to the canine and can only be distinguished by size (Figure 3b, 1st and 2nd from left in petri dish). Premolar P^2 (Figure 3b, 3rd from left in petri dish) is relatively large in both the upper and lower jaws and had a strongly developed anterior cusp giving

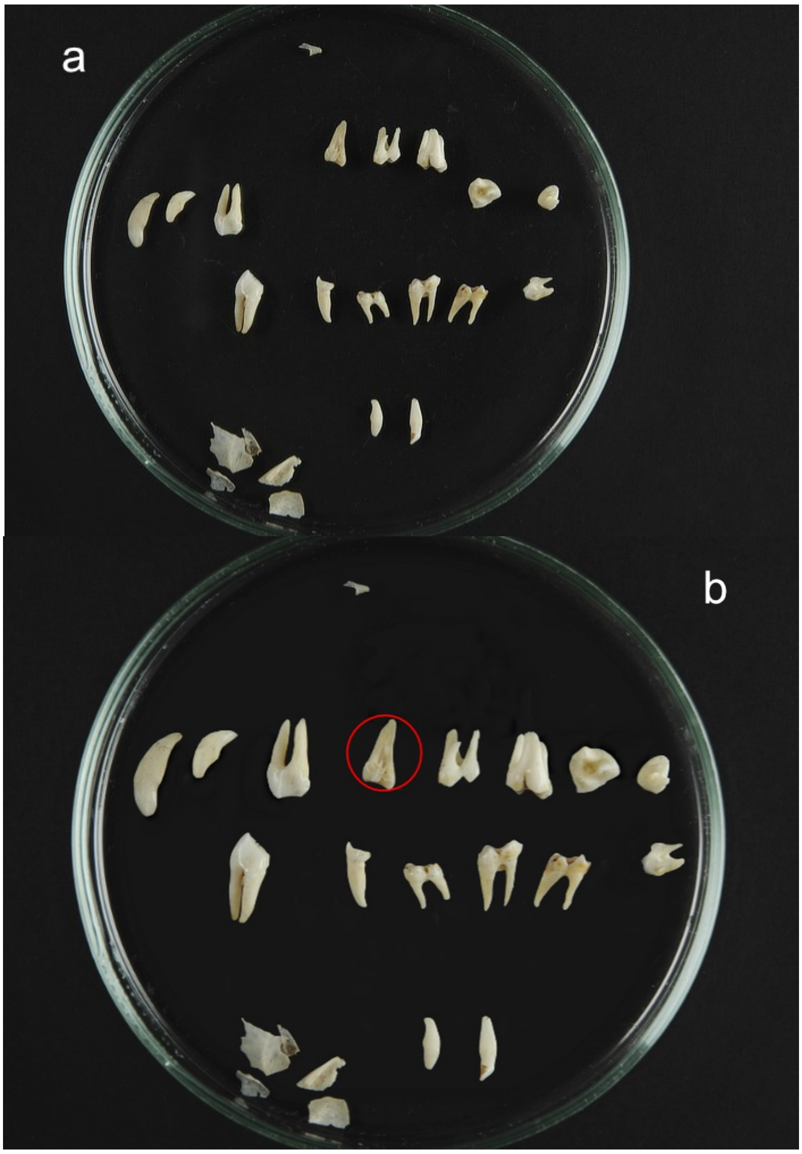

Figure 3. Teeth of Trichosurus vulpecula *a) left, initial sort after incisors have been placed, b) right, the most likely tooth sequence. The circle indicates a broken tooth, only half of which is present.*

it a very distinctive, pointed appearance. This is particularly noticeable on the lower tooth, which is also orientated obliquely in the mandible. It served as the next reference point in the tooth arcade.

In the petri dish, the remaining posterior teeth were more alike; therefore, three-rooted teeth were provisionally assigned to the rear upper quadrant because maxillary molars are often tri-radiate compared to the bi-radiate premolars and mandibular molars. Arrangement by size indicated the likely position of the remaining teeth, and a dry fit helped to confirm positioning before reattachment. It was immediately apparent if there was a slight misalignment or a poor fit, as the roots of the teeth fit closely to the bone. If there was any doubt, substituting a similar tooth from the dish invariably produced either a better result or confirmed the original choice. The positions of the four upper and four lower molars were established in this manner, as well as the upper M^4 missing from the right-hand maxilla (left, Figure 2 and Figure 4).

The finished quadrants were all complete except for the very small mandibular i_2, a tooth so small that it is unlikely to be found, but which should be located immediately behind the large lower incisor (the empty alveolus can be seen on the dissected side, Figure 4). A half tooth (Figure 3b, circled in petri dish) was found to be lower m_2 in the dissected mandible (there is a gap after the 3rd tooth). This tooth was broken into two (the other half is still missing), and consequently it was difficult to identify. Its position only became apparent when the other teeth were matched to their respective sockets. The tooth below it in the dish was not part of the set and neither were the two caniniform teeth shown at the bottom of the dish in Figure 3b.

The Museum of Life Sciences has many skulls which have teeth that are loose and sometimes fall out completely, so that it is easy to assume that sockets of the skulls and the teeth which fit into them are not particularly close-fitting. However, the developmental processes that direct the alveolus of the tooth to develop and to bind around the developing root are precise and most exacting (Tomes, 1923). Once the periodontal ligament, which binds the tooth into the alveolus is destroyed during preparation, the tapering, conical form of the roots can cause the teeth to fall from the upper set under the influence of gravity alone, even with the most perfect fit. By ensuring the correct combination of tooth morphology and unique physical fit between tooth and socket, we can be certain that the specimen has been reconfigured correctly, and that the few teeth which remained in the dish upon completion are from other specimens in the collection.

One species or two? Historical taxonomy

All four quadrants of the third specimen were found over time: first a skull and mandible pair, then a skull quadrant, and finally a loose mandible; each matched successively with the rest. Most teeth were present, and there was no conservation required beyond finding all four quadrants (Figure 5). The few missing teeth have not yet been located. Without doubt, these are the most ornate set of teeth in the collection but also the strangest. The specimen was donated in 1904 and is listed in our records as *Galeopithecus volans,* a species name that is no longer in use.

Figure 4. The completed quadrants of Trichosurus vulpecula. *(Quarters numbered using ISO3950/FDI nomenclature, ISO 2016).*

Figure 5. Two half skulls of Cynocephalus volans *(Linn., 1758) (left) and Galeopterus variegatus (Audeb., 1799) (right).*

The dental formula for the extant Dermopterans is (Berkovitz and Shellis, 2018; Stafford and Szalay, 2000):

$$\frac{2.1.2.3}{3.1.2.3}$$

George G. Simpson reorganised the classification of the order Dermoptera in 1945. He deprecated the family *Galeopithecidae* and replaced it with the *Cynocephalidae,* a name which had priority. Within it he re-established the use of two extant generic names, *Galeopterus* and *Cynocephalus*. The generic name *Galeopithecus* was synonymised, which caused a problem of identification; was our specimen now *Galeopterus* or did it follow the specific epithet, *Cynocephalus volans*? However, in his book he provides the answer: '*Galeopithecus volans =Cynocephalus volans*' (Simpson, 1945). Both species are known as colugo or 'flying lemurs', though they neither fly nor are they lemurs.

All the teeth, including the incisors and canines, are multi-cusped (Owen, 1845; Peyer, 1968). The first incisor, I^1, is always absent, causing an edentulous gap on the mesial palate (Stafford and Szalay, 2000; Berkovitz and Shellis, 2018). Consequently, the first two upper anterior teeth are I^2 and I^3. In the image above (Figure 5), the upper first tooth in each row (I^2) is different in both the left skull quadrant and the right skull quadrant, suggesting that we have a half specimen of each genus: *Cynocephalus* (left) with two tines (Stafford and Szalay, 2000) and *Galeopterus* (right) with three vertical tines (Owen, 1845; Stafford and Szalay, 2000).

In the Dermoptera, the third anterior tooth is the upper canine (Fig. 5). This tooth is unusual in that it has a biradiate root (as does the preceding I^3), which is not common amongst mammals. However, in *A Manual of Dental Anatomy,* C.S. Tomes states, by way of explanation, that such forms of teeth are more frequently seen in the paleontological record, which indicates that the Dermoptera are an ancient lineage (Tomes, 1923).

Mounting and labelling

In some cases, the historical documentation can be matched to the specimens under review, and this aspect of the project is ongoing. The 9000 numbers which appear in Table 2 (P no.) are the original specimen numbers allocated in the 'List of Donors and Donations'. The range 9000-9999 was allocated to the Comparative Anatomy section of the LSDS collection ('Special Catalogue'), which also included many other dental materials, human teeth, pathological tissues, etc. Each section of the collection was issued with its own 7xxx, 5xxx, etc. numbering system, so that each class of teaching specimen (e.g., dental pathology, etc.) had its own range of catalogue number. There are many discrepancies in the records, but at least some of the specimens can be positively identified (Table 2).

Suitably sized acrylic boxes from a variety of sources were used so that the quadrants could be protected, and each specimen was mounted onto Plastazote foam according to the arrangement shown in the figures above (Figures 2-5) and inserted into the base of the box. We intended to mount some smaller specimens onto a Perspex sheet, which was to be cut and polished to form a

Table 2. List of quadrant specimens identified to date (P no. = original specimen number)

Genus	specific epithet	Authority, date	P no	Donor	Quadrant
Melanosuchus	*niger*	(Spix, 1825)	9114	Austin, H., 1907	Q1,Q2,Q3,Q4
Didelphis	*virginiana*	(Kerr, 1792)			Q1
Sarcophilous	*harrisii*	(Boitard, 1841)			Q3
Trichosurus	*vulpecula*	(Kerr, 1792)	9033		Q1,Q2,Q3,Q4
Phascolarctos	*cinereus*	(Goldfuss, 1817)	9004	Tomes. c1900	Q1,Q2,Q4
Erinaceus	*europaeus*	Linn., 1758	3.5.6/5		Q3
Galeopterus (Galeopithecus)	*variegatus*	(Audeb., 1799)	9140	Hopewell Smith, A., 1904	Q1,Q2,Q3,Q4
Indri	*indri*	(Gmelin, 1788)	9005	Tomes. c1900	Q1,Q2,Q3,Q4
Presbytis		Eschsch, 1821			Q1, Q2
Herpestes	*ichneumon*	(Linn., 1758)			Q2,Q3
Lutra	*lutra*	(Linn., 1758)			Q1,Q4
Enhydra	*lutris*	(Linn., 1758)	9182	Students Society, 1907 [248]	Q1,Q2,Q3,Q4
Hyaena		Brisson, 1762			Q1,Q4
Felis	*catus*	Linn., 1758			Q2,Q3
Dasypus (Tatusia)	*novemcinctus*	Linn., 1758	9000	Tomes. c1880-1900	Q1
Dolichotis		Desmarest, 1820		Unknown, pre-1958	Q1,Q/2,Q3
Hydrochoerus		Brisson, 1762			Q1, Q2,Q3
Procavia	*capensis*	(Pallas, 1766)	9100	Pritchett c1907	Q1,Q4
Tapirus		Brisson, 1762			Q4
Equus	*ferus*	Boddaert, 1785			Q2
Babyrousa	*babyrussa*	(Linn., 1758)			Q1,Q4
Sus	*scrofa*	Linn., 1758			Q1,Q4
Ovis	*aries*	Linn., 1758			Q1,Q4

Quadrants:	Q1: Upper right	Q2: Upper left
	Q4: Lower right	Q3: Lower left

mounting plate of suitable size to fit into the box. However, we were unable to commission the work because of the Covid-19 pandemic. This part of the project has been postponed until it can be investigated in more detail, and Plastazote was used as an immediate solution.

The cranio-facial collection was catalogued at least three times previously. Unfortunately, none of these systems is comprehensive; each covers a narrower sub-section of the collection, so that there is some information in each of the three systems. Currently, some specimens have old labels which are faded or are missing completely, so they must be re-identified using the paper record or other reference materials. A small label has been prepared for this project as a pilot for the rest of the collection to assess the feasibility of adding additional collection information. Labels needed to be small enough in size not to overwhelm the specimen itself. However, the inclusion of as much information as possible from previous, historical labelling systems will make the Museum of Life Sciences historical documentation more accessible.

Conclusion and Further Work

This project has successfully reassembled, as far as possible, three specimens from the original teaching collection of the RDS and prepared them for display so that they can be viewed safely. Other specimens are in the process of being similarly prepared. A long-term goal now is to combine all the data into one comprehensive database. In the short-term, however, we are trialling a labelling system which will enable access to the data from the various historical catalogues. This is still at a provisional stage of development, but identification of the specimens and the correlation between original documents and specimens has been established and should become more apparent as work continues. While these specimens are too delicate to be used regularly for teaching today, they are valuable demonstration material and of interest to historical researchers looking to better understand early methods of teaching dental surgeons.

The paper records which relate to many of the specimens contain valuable data which link the specimen to the well-documented historical record of the Odontological Society and thereby form a unique set which will be preserved, collated, and re-assembled as part of the Museum of Life Sciences collection. For example, there is a specimen of a hippopotamus skull which has been dated to 1859, and we have been able to match paper records to some specimens donated by Charles Tomes, Morton Smale, and Arthur Hopewell Smith, who were all members of the Odontological Society and therefore associated with the RDH from 1880 until 1930. We will attempt to link other donors to particular specimens to give a unique record of this special collection.

Acknowledgments

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Recreating a long-lost herbarium

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Abstract

The Horticultural Society of London (now the Royal Horticultural Society (RHS)) sold its herbarium collection at auction in 1856. The collection was made up of specimens collected by its sponsored plant collectors in addition to a number of donated collections. This paper attempts to recreate the lost herbarium virtually by tracking down the current location of the RHS's set of specimens via the sales catalogue. The RHS's Lindley Library still holds many of the journals made by the collectors, along with accessions registers for many of the plants that made their way into our gardens. As these become digitised and available to researchers via the RHS's web portal it should soon be possible to enhance the notes, dates of collection and geographic localities that are sadly lacking on the actual specimens.

Keywords: herbarium, RHS, David Douglas, Robert Fortune, George Don

Introduction

Early on a very cold but dry afternoon in January 1856 (Whymper, 1856) botanists and their agents gathered in London at 38 King Street, Covent Garden, to participate in an auction of arguably, for horticulture, the most important collection of dried plant specimens ever to be sold . These collections are not only of huge scientific significance to taxonomists but also to horticulturists as they were the source of a great many of the plants that are still growing in our gardens today (Harvey and Gregson 2016: 121-123). The auction comprised 54 (plus 2) Lots (Figure 1 and 2) of plants from the Arctic to the Cape, the majority of which had been made by plant collectors sponsored by the Horticultural Society of London. The expectation was to make the dried plant collection of the Society more accessible to researchers as it was anticipated to be sold to some of the larger herbaria.

The specimens had merely been made to aid identification and naming of the plants and seeds sent back to the UK to introduce to gardens (Gardeners' Chronicle 1856: 68), and as that purpose had been successfully served, they were no longer of use to the Society. The report in the Gardeners' Chronicle cited above neglected to mention the financial difficulties that the Society was experiencing that necessitated the sale. Regrettably until recently their new locality was unknown to the Royal Horticultural Society (RHS) as 'no record has been found of the purchasers of the specimens; many may lurk unidentified in private collections' (Elliott 2004: 224). Now that we have reached a time when a number of collections have been or are in the process of being digitised it should be possible to find the collection and recreate the Royal Horticultural Society's long-lost herbarium virtually.

Background

The Royal Horticultural Society (RHS) was formed in March 1804 for the purpose of instituting a Society for the improvement of horticulture and that the objections of the new Society should be 'to collect every information respecting the culture and treatment of all plants and trees as well as culinary as ornamental;' 'to foster and encourage every branch of Horticulture, and all the arts connected with it;' and 'that it shall be considered within the intention of the Society to give premiums for improvements in Horticulture, wherever it should be judged expedient to do so.' (Murray 1868: 9). From its start of 91 members elected in the first year, the Society still continues to this day with a considerably larger membership of over 600,000.

From 1804, plant collecting opportunities outside of the UK were initially hindered by transport difficulties caused by the Napoleonic wars. When peace came in 1815, the Society began to obtain valuable foreign plants from outside of continental Europe, and these were shipped to the UK from Fellows and friends of the Society based abroad, and then distributed to the members (Murray 1868: 14). A large number of these early imports, such as *Wisteria sinensis* and many varieties of camellias, azaleas, roses and chrysanthemums are still known and grown today. However, it is a feat that any living plant should have survived the voyage as the 'Wardian Case' (see Keogh, 2020) had yet to be invented, and plants were frequently heaved overboard when the return voyages hit ferocious weather conditions. Letters between Dr John Livingstone, the chief surgeon of the East India Company in China and Joseph Sabine, Secretary of the Society, about the difficulties of transport led to an idea being formed of sending gardeners to the tropics to collect and subsequently care for living collections during their time in transit to the UK (Fletcher 1969: 93-94). John Potts was the first of these and was sent to China and India in the spring of 1821. His first shipment of plants, seeds and dried specimens arrived in the UK from Calcutta in February 1822. Potts's success was followed by a series of collectors until 1864. In order of employment, the successive plant hunters were George Don, John Forbes, John Damper Parks (occasionally spelt Parkes), David Douglas, James MacRae, Karl Theodore Hartweg, Robert Fortune, Matteo Botteri and John Weir. All of the collectors made herbarium specimens of plants taken for cultivation to enable correct names to be attached to the new introductions. They were also given permission to make duplicate sets of specimens that could be sold, the profit staying with the collector.

The Society's finances were such that in 1818 an experimental garden was established at Kensington and an auxiliary nursery at Ealing. In March 1822 (Elliot, 2004) [March 1823 according to Fletcher (1969: 80)] the Society relinquished these gardens after it obtained a lease on a 33 acre garden at Chiswick (Murray 1868: 12-13). The new garden had greater provision for stove plants and its ever-increasing numbers of glasshouses were filled almost entirely with plants acquired by the Society, especially by those of the early plant collectors it had commissioned. Also stored at Chiswick, in the garden's house, were the 'top set' of herbarium specimens made at the time of collection by the Society's plant collectors. This collection was enhanced by donations from others, mentioned in the appendices of the *Transactions of the Horticultural Society of London* (vol. 5 (1824) and vol. 6 (1826)).

The need for more glasshouses, and the downturn in income owing to the success that the Royal Botanic Gardens, Kew was having in pulling the crowds away from the Chiswick Garden (Fletcher 1969: 153-154) aided the decision to auction the herbarium. From George Bentham's diary, held in the Archives of the Royal Botanic Gardens, Kew, can be seen evidence of the excitement and anticipation that the auction generated. Bentham, the Society's Secretary at the time of the auction, mentions a trip to the Society's Chiswick Garden, taking the Hookers of Kew (William and Joseph) to have a look at the Lots prior to their sale (21st January 1856) (Figure 1), and after sale distribution of bundles to eminent botanists of the day (Figure 2).

As mentioned above, little was known of where the herbarium collections were sent after they were sold in 1856. And nothing is known of the actual number of specimens that the Society held. The collectors are known, and as a consequence it should have been possible to look up their type specimens on JSTOR's Global Plants website (http://plants.jstor.org/). However, owing to the many duplicates made by collectors, it was not possible to say where the actual RHS set went. Discovering Robert Brown's annotated copy of the sales catalogue held at London's Natural History Museum in mid-2016, and more recently, John Lindley's annotated copy of the sales catalogue at the RHS's Lindley Library (Figures 3 and 4) has led to the discovery of the herbaria where the majority of the specimens eventually went. *Index Herbariorum* (1990: 513-556) has helped trace subsequent moves. With the purchase of John Lindley's herbarium in 1866 (see Gardiner, 2018), the Cambridge University Herbarium holds the most comprehensive set of duplicates of the Collectors' specimens (inferred

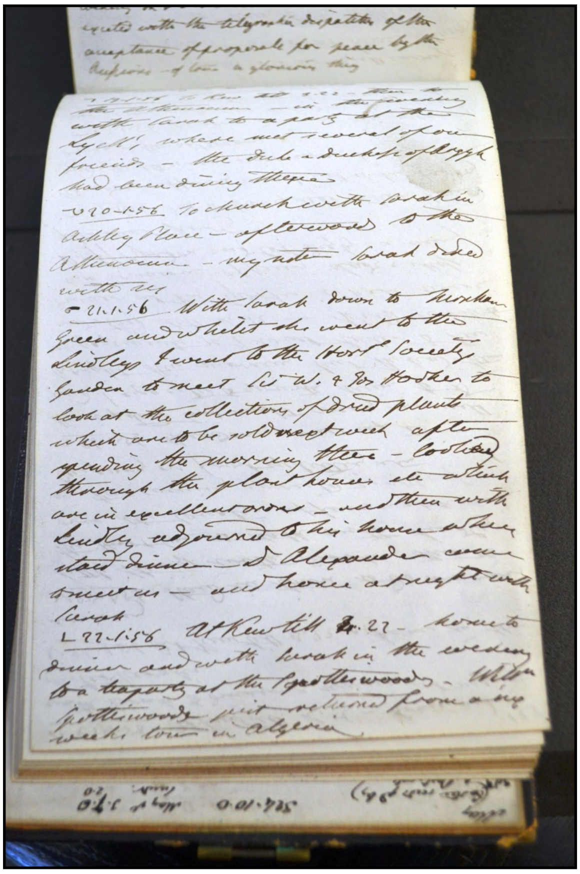


Figure 1. George Bentham's diary entry for 21st January 1821 when he accompanied Sir William and Joseph Hooker to Chiswick to view the auction Lots © Yvette Harvey

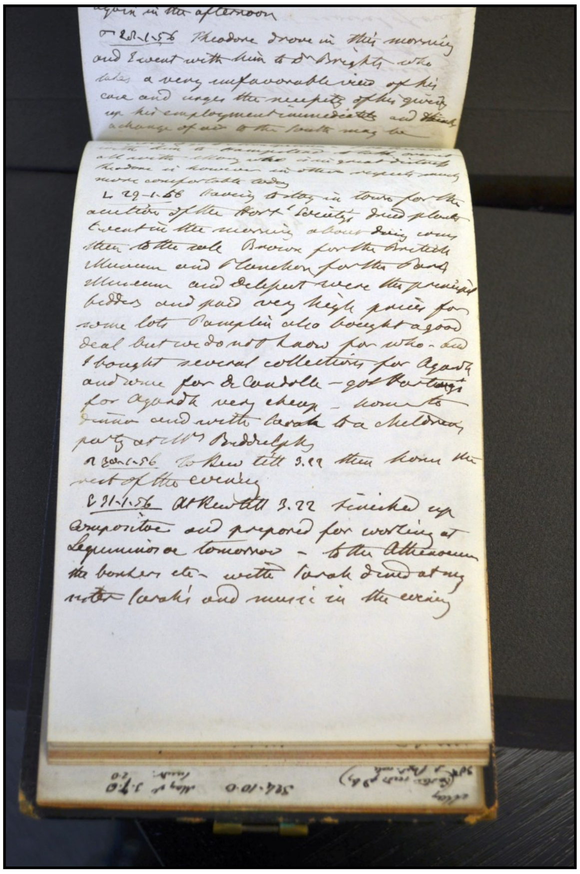


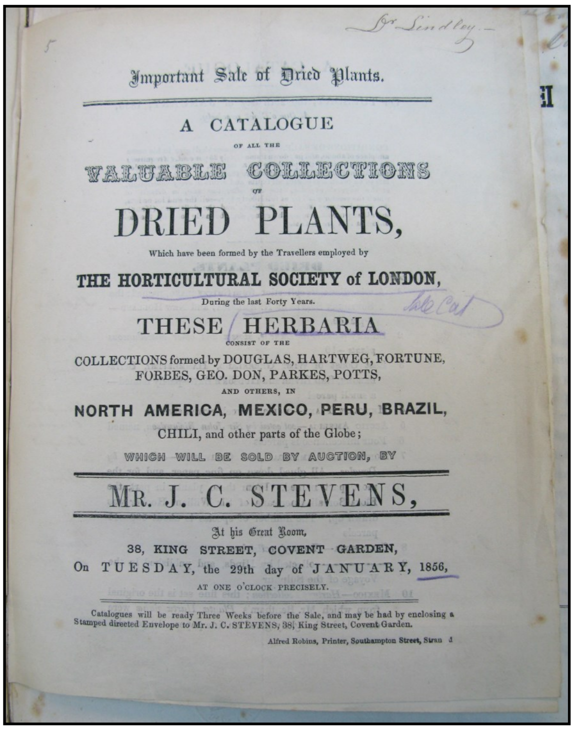
Figure 2. George Bentham's diary entry on the sale day, noting Lots that he purchased © Yvette Harvey

from Lindley's primary position in the Bentham archive's Hartweg duplicate distribution list (Figure 5)) in addition to specimens that were made from plants grown on from seed and depicted in *Botanical Register*.

The RHS's Lindley Library still holds many of the journals made by the collectors, along with accessions registers for many of the plants that made their way into our gardens. As these become digitised and available to researchers via the RHS's web portal it should soon be possible to enhance the notes, dates of collection and geographic localities that are sadly lacking on the actual specimens.

Current locations of the Horticultural Society of London's herbarium

The first section takes a chronological look at the collecting trips of the sponsored collectors, in the order in which their expeditions took place. Herbaria are given their formal name and standard abbreviation in brackets at first mention and are subsequently named by their abbreviation (for example BM is the code for the Natural History



Dr Lindley

Important Sale of Dried Plants.

A CATALOGUE

OF ALL THE

VALUABLE COLLECTIONS

OF

DRIED PLANTS,

Which have been formed by the Travellers employed by

THE HORTICULTURAL SOCIETY of LONDON,

During the last Forty Years.

THESE HERBARIA

CONSIST OF THE

COLLECTIONS formed by DOUGLAS, HARTWEG, FORTUNE, FORBES, GEO. DON, PARKES, POTTS,

AND OTHERS, IN

NORTH AMERICA, MEXICO, PERU, BRAZIL, CHILI, and other parts of the Globe;

WHICH WILL BE SOLD BY AUCTION, BY

MR. J. C. STEVENS,

At his Great Room,

38, KING STREET, COVENT GARDEN,

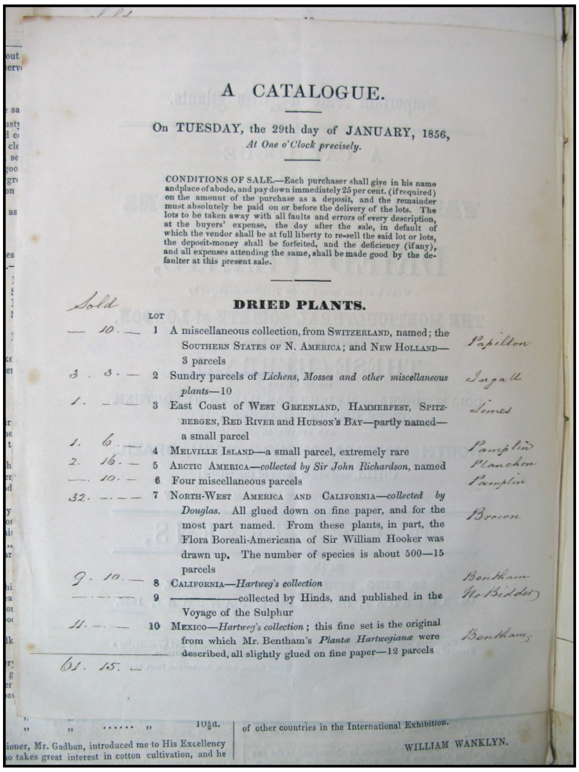
On TUESDAY, the 29th day of JANUARY, 1856,

AT ONE O'CLOCK PRECISELY.

Catalogues will be ready Three Weeks before the Sale, and may be had by enclosing a Stamped directed Envelope to Mr. J. C. STEVENS, 38, King Street, Covent Garden.

Alfred Robins, Printer, Southampton Street, Stran

Figure 3. Title page of John Lindley's copy of the Sale catalogue © RHS Lindley Library



A CATALOGUE.

On TUESDAY, the 29th day of JANUARY, 1856,
At One o'Clock precisely.

CONDITIONS OF SALE.—Each purchaser shall give in his name and place of abode, and pay down immediately 25 per cent. (if required) on the amount of the purchase as a deposit, and the remainder must absolutely be paid on or before the delivery of the lots. The lots to be taken away with all faults and errors of every description, at the buyers' expense, the day after the sale, in default of which the vendor shall be at full liberty to re-sell the said lot or lots, the deposit-money shall be forfeited, and the deficiency (if any), and all expenses attending the same, shall be made good by the defaulter at this present sale.

DRIED PLANTS.

Sold	LOT		
— 10. —	1	A miscellaneous collection, from SWITZERLAND, named; the SOUTHERN STATES OF N. AMERICA; and NEW HOLLAND—3 parcels	Papillon
3. 3. —	2	Sundry parcels of *Lichens, Mosses and other miscellaneous plants*—10	Ingall
1. — —	3	East Coast of WEST GREENLAND, HAMMERFEST, SPITZBERGEN, RED RIVER and HUDSON'S BAY—partly named—a small parcel	Simes
1. 6. —	4	MELVILLE ISLAND—a small parcel, extremely rare	Pamplin
2. 16. —	5	ARCTIC AMERICA—*collected by Sir John Richardson*, named	Planchon
—. 10. —	6	Four miscellaneous parcels	Pamplin
32. — —	7	NORTH-WEST AMERICA AND CALIFORNIA—*collected by Douglas.* All glued down on fine paper, and for the most part named. From these plants, in part, the Flora Boreali-Americana of Sir William Hooker was drawn up. The number of species is about 500—15 parcels	Brown
9. 10. —	8	CALIFORNIA—*Hartweg's collection*	Bentham
— — —	9	————collected by Hinds, and published in the Voyage of the Sulphur	No Bidder
11. — —	10	MEXICO—*Hartweg's collection*; this fine set is the original from which Mr. Bentham's *Plantæ Hartwegianæ* were described, all slightly glued on fine paper—12 parcels	Bentham
61. 15. —			

Figure 4. Second page of Lindley's Sale Catalogue. Note the annotations alluding to buyers and prices paid © RHS Lindley

Museum, London) Within botany, all herbaria of over 10,000 specimens are assigned a standard abbreviation or acronym. Since 1952 *Index Herbariorum* (see Lanjouw *et al.,* 1952) has been published, initially in printed form, currently online (see Thiers), listing all of the world's herbaria with their abbreviation(s). The second section is devoted to donated collections that were also part of the Society's collection at the time of auction. The final section looks at miscellaneous collections.

The Society's collectors

John Potts (-1822)

John Potts was the first of the Society's salaried plant collectors. In January 1821 he joined Captain Alexander Nairne's round trip on the East India Company's sloop, H.C.S. General Kyd. The voyage went to India, Malaysia, Malacca, Singapore, China and St. Helena before returning to the UK in July 1822. In Canton Potts liaised with John Reeves, an East India Company tea factor who had previously sent plants to the Society. Reeves introduced Potts to a range of suppliers. At that time, foreigners were only allowed access to a few Chinese towns and whilst there Potts had to move rapidly from Canton to Macao during a period of civil unrest.

Figure 5. Hartweg's duplicate distribution list held in Bentham's archive at the Royal Botanic Gardens, Kew © Lulu Rico

Potts's first shipment of plants, seeds and dried specimens arrived in the UK from Calcutta in February 1822. His journey was a success and he brought back a large stock of Chinese and East Indian plants, many of which were named in his honour.

Potts's herbarium collection was auctioned in two separate lots. Lot 29, his East Indian plants, were sold to J. Sowerby for £1 1'. Sowerby's herbarium was passed to the Natural History Museum, London, UK (BM). The Chinese plants (Lot 35) were purchased by Daubeny for a similar sum and are in University of Oxford, UK (OXF).

George Don (1798-1856)

In the winter of 1821, George Don, foreman of the Chelsea Physic Garden, travelled on HMS Iphigenia and subsequently HMS Pheasant with an expedition team tasked with collecting data on the calculation of time in different localities. The team was led by the secretary of the Horticultural Society's brother, Captain Edward Sabine. Don's archive holds journals, letters, instructions, expenses, shipping lists, notes and also letters from Edward Sabine to his bother in London.

The expedition followed a path around the West coast of Africa to Equatorial Guinea and then across the Atlantic to Brazil, and up to New York before returning to England in early February 1823. Don's participation in the voyage was nearly curtailed before they had even left England when he missed the sailing time from Brixham. Fortunately he was able to catch the vessel at the final UK port of Plymouth following a rather fraught dash. Don had many adventures on the trip, particularly in Africa: the HMS Iphigenia intercepted vessels carrying recently enslaved people in West Africa; he met the last original surviving 'Nova Scotian' settler in Sierra Leone; dined with James Bannerman, the son of a Fanti mother and a Scottish father who was a successful merchant and subsequently the governor of Accra; survived numerous tropical illnesses that wiped out many of his fellow travellers; and joined two of Dr Hosack's legendary Saturday evening meetings (14th and 28th December.1822) (see Johnson, 2018) whilst in New York.

The Society broke up and auctioned his collection in a number of different Lots based on geographic location. Combining penned remarks on each of the catalogues, it is possible to trace all but two of the Lots. The largest collection, from the West Coast of Africa was purchased by Brown for the BM. Pamplin, who was buying on behalf of Grisebach, secured collections made at Ascension Island, Havana, Madeira and Tenerife. Grisebach's herbarium is housed at Universität Göttingen, Germany (GOET). According to Brown's note on the Natural History Museum's catalogue, Bentham was Agardh and De Candolle's agent and purchased Lots from Trinidad, Maranhao and Bahia. These collections should be found in the main herbaria in Lund University, Sweden (LD) and Conservatoire et Jardin Botaniques de la Ville de Genève, Switzerland (G) although desktop searches of their incomplete catalogues haven't found any specimens at either institution. The entry for 5th April 1856 in Bentham's diary stored in the Archives at Royal Botanic Gardens, Kew, implies that Bentham was also buying on behalf of Martius 'To Kew till 4.10 I sent off a box to Martius with Lots we returned – Don's Maranhao plants which I bought for him, a parcel of Spruce's plants and Hookers' Flora Australiem [sic] my duplicate copy which I gave him'. Indicating that the specimens will be in the Meise Botanic Garden herbarium, Belgium (BR) (see Förther, 1994)). Brown's catalogue doesn't list the buyer of the Bahian Lot. Lindley's catalogue lists Bentham, so it is likely that the Bahian collections were also purchased for Martius. The specimens from Cape Verde (Santiago) were taken by 'Hooker' and are at the Royal Botanic Gardens, Kew, UK (K). The collections purchased by Roberts are proving more elusive to find. Made in Jamaica and Grand Cayman, they are untraceable at present.

John Forbes (1799-1823)

John Forbes, former apprentice at the Liverpool Botanic Gardens became the Society's third plant collector, joining the HMS Leven, a 20-gun sixth rate Cyrus-class post ship, under the command of Captain W.F.W. Owen, tasked with making a survey of the east coast of Africa. The ship embarked on 4th February 1822 and visited (in the following order) Madeira, Teneriffe, Santa Cruz, Cape Verde Islands, Brazil, South Africa, Mozambique (Forbes is noted as the second botanist to collect there (Exell and Hayes: 130)), Madagascar (1822-1823), Comoros, Mozambique, South Africa and Mozambique (where Forbes died, 16th August 1823) (see Figueiredo and Smith (2022)). All of his dried collections, with the exception of his final sub-expedition up the Zambezi, returned to the Horticultural Society for distribution. The Society still has his journals (used extensively by Owen (1833) in his narrative of the voyage), letters, note books, collecting lists and other archive papers. A reference is made of Forbes's botanical excursion (via his travelling companion, Georg Langsdorff) to the foot of the Organ Mts in Brazil by Gardner (1846: 62). It is unlikely that Forbes's Brazilian collections were seen by Martius during the writing of Flora Brasiliensis since he is not mentioned in the list of collectors (1906: 1(1)), however, plates published in Botanical Register of Forbes's Brazilian collections are cited in Flora Brasiliensis (see Cogniaux (1901: 226 and 1902: 468)).

In catalogue order, specimens collected in Brazil were purchased by Sowerby and can be found at the BM. Collections from the Cape of Good Hope (South Africa) and Delagoa Bay (Mozambique) were purchased by Planchon, whose collections are at Université de Montpellier, France (MPU). Brown secured collections from Algoa Bay (South Africa) and Madagascar for the BM. Further collections from Mozambique ('east coast of Africa') were sold to Bentham who was acting as agent on behalf of Agardh for LD and de Candolle for G. Forbes collections from Madeira, Teneriffe and Cape Verde (St. Jago [Santiago]) were purchased by Money [possibly W. Money of 53 Borough, London, UK, who was corresponding with Pamplin in May 1869] and have yet to be traced.

John Damper Parks (c.1791-1866)

In 1823 John Damper Parks joined Captain Thomas Baker on the 7th voyage to China of the East India Company's Clipper ship, the Lowther Castle. Tasked with taking a number of fruit trees and ornamentals to China, and returning the following year with the double Banksian rose, *Chrysanthemum* and *Camellia japonica* cvs. Regrettably many of the plants being taken to China had perished early in the voyage (peaches, nectarines, violets, rhubarb, plums and *Passiflora*) owing to saltwater ingress in the Lindley designed cases. As a consequence Parks made a number of adjustments and made extensive notes on plant survival during a voyage, and these informed subsequent journeys undertaken by the Society's collectors. A great note-taker, Parks also provided the Society with extensive passages on Chinese horticultural techniques.

The auction catalogue lists two Lots for Parks specimens, Lot 34 of 17 parcels (4 of which were duplicates) sold to Bentham, and Lot 38 of specimens from Java that has no buyer listed although it went for £10. Regrettably, at present no sets have been traced.

David Douglas (1799-1834)

David Douglas undertook three separate collecting trips for the Society, ultimately all to America. Douglas is traditionally known for changing the English landscape with his introductions of conifers. His first trip for the Society was from June 1823 to January 1824 and was to collect fruit trees and gather information on the latest developments in fruit growing (Fletcher 1969: 100). Along with visits to gardens, orchards, nurseries and leading American horticulturists, Douglas did find time to botanise too. Following the success of his first trip, the Society sponsored his second trip to the Pacific Northwest (via Madeira, Rio de Janeiro, Cape Horn, Juan Fernandez and the Galapagos Islands) from July 1824 to October 1827. He was under the protection of the Hudson Bay Company and based at Fort Vancouver on the Columbia River and had many death defying adventures, particularly during his final overland journey from Vancouver to Hudson Bay. This expedition was an overwhelming success as he introduced over 200 taxa to gardens (see Figures 6, 7 and 8), including *Lupinus polyphyllus* and *Ribes sanguineum*. His third and final expedition

Figure 6. David Douglas's Penstemon venustus *collected from 'dry channels of the Rivers in the Blue Mountains'. The Horticultural Society of London's specimen that was purchased by Brown for the Natural History Museum in London (Lot 7). © The Trustees of The Natural History Museum, London https://data.nhm.ac.uk/object/346e0768-71ab-4233-8397-88c8131e95c7/1671667200000*

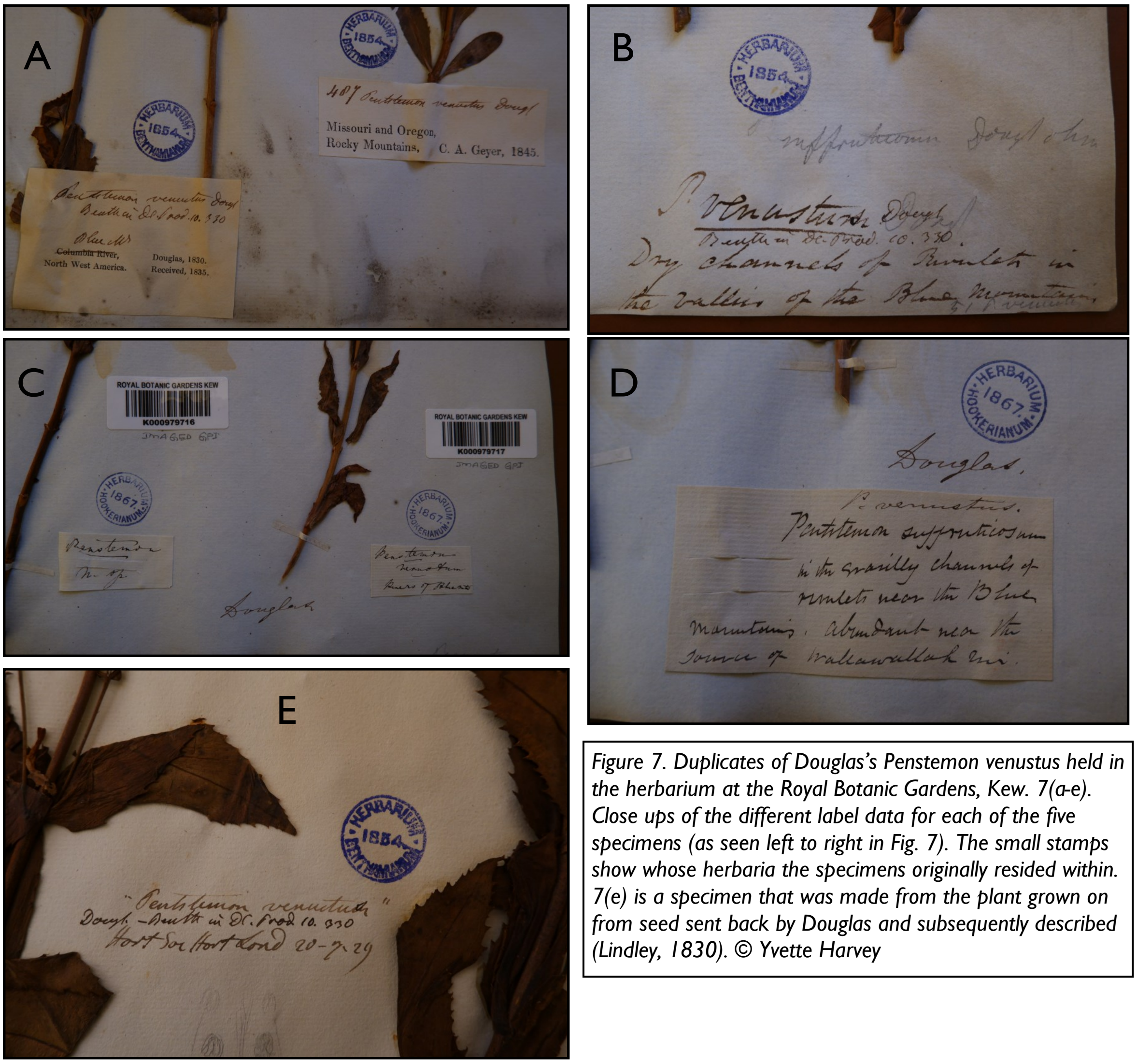


Figure 7. Duplicates of Douglas's Penstemon venustus held in the herbarium at the Royal Botanic Gardens, Kew. 7(a-e). Close ups of the different label data for each of the five specimens (as seen left to right in Fig. 7). The small stamps show whose herbaria the specimens originally resided within. 7(e) is a specimen that was made from the plant grown on from seed sent back by Douglas and subsequently described (Lindley, 1830). © Yvette Harvey

for the Society was to California and was from October 1829 to 1832 (when he resigned whilst in Hawaii). Douglas's herbarium collections were sold in different Lots. Lot 12, his first trip had no bidder. The American collections made during his 2nd and 3rd trips were purchased by Brown for the BM (see Figure 4). Lot 25 contained collections made near Rio de Janeiro and were purchased by Pamplin on behalf of Grisebach (GOET). Douglas's Chilean collection went to George Bentham, the agent buying on behalf of Agardh (LD) and de Candolle (G). Lots 1 and 3 contained misc. collections and will almost certainly have included Douglas duplicates. Lot 1, including plants from the Southern States of N. America was sold to an unknown party. Lot 3, with specimens from the East Coast of West Greenland and Hudson's Bay was purchased by 'Syme' and also remains untraced.

James MacRae (b.unk-1830)

James MacRae was the horticulturist on board of the HMS Blonde, under Captain George Byron, tasked with repatriating the bodies of King Kamehameha II and Queen Kamāmalu of the Kingdom of Hawaii who had died while trying to visit King George IV. The voyage left the UK in September 1824 and returned in March 1826. Taking in Madeira, Brazil, Chile, Galapagos Islands, Hawaii, Chile (again) and St Helena, it was quite an adventure as the ship had a mutiny, and also took on board passengers from a stranded vessel, the survivors who had only lived by eating their dead companions (including a fiancé). MacRae was the horticulturist performing the diplomatic function of keeping fruit trees and other plants alive on their voyage to Hawaii. In addition, he collected plants of horticultural value during the voyage. Although previously discovered by Menzies, it was MacRae's seed that established the Monkey Puzzle as a tree of merit in the UK.

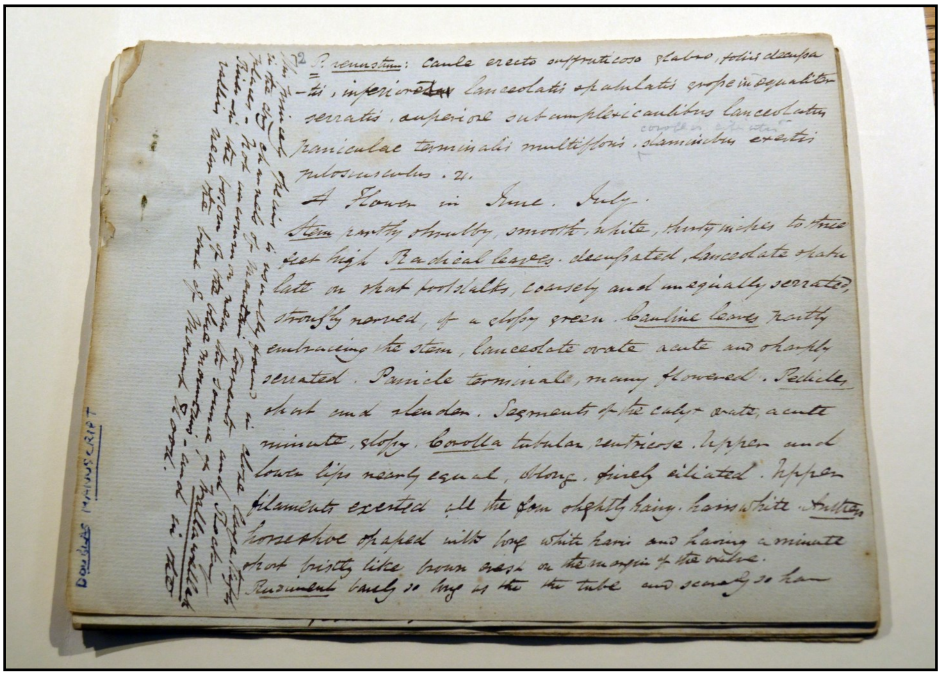


Figure 8. Passage from Douglas's unpublished manuscript held by the RHS Lindley Library. Here he describes the locality of Penstemon venustus 'near the source of Wallawallah River in the bosom of the Blue Mountains – and in the valley near the base of Mount Hood'. © RHS Lindley Library.

The auction catalogue has numerous listings for MacRae's herbarium collections, including duplicates. The top set of Hawaiian specimens were purchased by Brown (BM); Brazilian and St Helenan specimens by Pamplin for Grisebach (GOET); and Chilean collections by Planchon (MPU). Duplicates from Chile and Brazil were taken by Planchon (MPU) and unnamed duplicates including specimens from Hawaii and Chile went to Grisebach (GOET) via his buyer, Pamplin.

Karl Theodor Hartweg (1812-1871)

Hartweg undertook two expeditions to Central America for the Society. Tasked with collecting plants suitable for growing outdoors (orchids excepted), in 1836 he travelled around Mexico until the country became too unsettled (hostilities between Mexico and France), and then continued collecting in Guatemala, Ecuador, Colombia and finally Jamaica before returning to the UK in 1843. His next expedition was to California and Mexico (1846-48), at a time when the United States was claiming parts of Mexican territory, so was also fraught with difficulty. He introduced many of the ancestors of the modern hybrid *Fuchsia*, *Salvia, Lupinus* and *Penstemon* along with a number of conifers, orchids and cacti. The archives at the RHS Lindley Library include his correspondence, account books and other documents. The Chiswick garden accessions books are available to trace his introductions.

Hartweg was given permission to collect herbarium specimens on the understanding that it was not to interfere with the specific objective of his mission. For every 100 species he received £2 (McVaugh: 15). Collecting in sets of 20, the lists of subscribers and subsequent correspondence can be found in the Bentham archive, held at the Royal Botanic Gardens, Kew (see Figure 5). The duplicate sets are in the following herbaria: Kew (K) (Bentham's collection and Sir William Hooker's collection); Cambridge University Herbarium, UK (CGE) (Lindley's collection, Lemann's collection and Graham's collection); BM (their own set and Shuttleworth's collection); Herbarium Universitatis Florentinae (FI) (Lambert's collection and Webb's collection); OXF (Fielding's collection); Naturhistorisches Museum Wien, Austria (W) (Endlicher's collection); Naturalis Biodiversity Centre, The Netherlands (L) (Reinwardt's collection); G (Delessert's collection and Boissier's collection); Harvard University, USA (A) (Gray's collection); Komarov Botanical Institute of RAS, Russia (LE) (their own set); P (their own set) and ZE Botanischer Garten und Botanisches Museum, Berlin (B) (their own set). Other sets purchased by Harris and Saunders have yet to be traced. The set of specimens that belonged to the Horticultural Society of London was sold in two lots (8 and 10) and purchased for £20 10 shillings by Bentham buying on behalf of Agardh whose collection can be found in LD (searchable here: http://herbarium.emg.umu.se/standard_search.html).

Robert Fortune (1812-1880)

Most commonly known as the man who introduced tea to India whilst working for the East India Company, earlier in his career Robert Fortune collected extensively in China for the Horticultural Society of London. This was possible following the signing of the Treaty of Nanking on 26th August 1842, granting easier access to China (Ward 2003: 445-457). His transport, the Emu, set sail from Portsmouth on 1st March 1843 (1843: 345) and arrived in Hong Kong's harbour on 9th July (1844: 70). Fortune was tasked with collecting plants suited to a temperate climate (with the exception of orchids and 'plants producing very handsome flowers') (RHS archive); studying soils suitable for camellias, azaleas, chrysanthemum and *Enkianthus*; collecting seeds for distribution to Fellows; growing advice for 'Chinese dwarf trees'; and manure management amongst others. He was supplied with gardening tools and a firearm that was put to excellent use when a boat in which he was travelling was attacked by pirates (Fortune 1847: 396-398).

Fortune's herbarium was sold in two separate Lots. Lot 32 comprised his main collection of plants from Hong Kong, Chusan and other places and was sold for £9 5/- to Planchon (MPU). The second item, Lot 36 was of a small parcel of specimens of the Tea Plant collected by Fortune. This was sold to Papillon for 11/-. Although no trace can be found of 'Papillon' it seems likely that this might be a *nom de plume* for JC Stevens (his close relative was a keen butterfly collector (Allingham 1924: 129)), buying on behalf of John Lindley. A bundle filled with Fortune's tea plants has been discovered by Lauren Gardiner within Lindley's herbarium stored in the Cambridge University herbarium (CGE) (Gardiner, pers. comm.).

Matteo Botteri (1808-1877)

No longer selecting horticulturists, following a brief gap, the next plant collector to be chosen to collect on behalf of the Society was the Italian ornithologist, zoologist and botanist Matteo Botteri. He was tasked by the Society to collect plants in Mexico between 1854 and 1856 when his employment was terminated. His non-dried plant collecting was not overly successful as many shipments arrived in too poor conditions or the plants were of insufficient interest (Elliot 2004: 206). The RHS archives have a ledger containing his incoming collections, itemised by a clerk as they were removed from the packing crates. The RHS clerk didn't hold back with regard the state of the incoming material: record 178 [not Botteri's number sequence] *Tillandsia* sp. (broadleaved), "22 bits in very doubtful condition and nearly all dead"; and after record no. 212 "the plants were very dry and seem to have been long packed. They were thrown loosely into the chests, and some few, seem to have been numbered on bits of paper but which had mostly been detached on the journey". And for record 301 "nine small scraps of papers rolled up, with no names nor numbers and scarcely a seed in them. ? condition". Botteri's specimens were sold in one Lot to Planchon for £25, containing c. 1000 species. As noted earlier they should be found in MPU herbarium although a larger number are in P (*pers. comm.* Caroline Loup, curator of MPU).

John Weir (b.unk-1898)

Weir's collecting trips were undertaken after January 1856 and so were made outside the scope of this study.

Donated Collections

In the early years of the Society, Fellows were encouraged to donate plants, seeds, publications and other pertinent items of interest including herbaria. The auctioned items included donated herbarium specimens, some of which had been itemised in un-numbered pages at the end of two separate volumes of the *Transactions of the Horticultural Society of London* (v. 5 (1824) and v. 6 1826), along with others listed only in the auction catalogue (1856). Donor names are listed below as they appeared in either the *Transactions* (1824 and 1826) or the sale catalogue (1856).

James Brogden (b. unk – d. unk)

New Holland (1856). Purchased by Brown for the BM. It is likely that there also were duplicates that were sold within a different Lot purchased by Papillon (see above, likely to be at CGE).

Lieut John Henry Davies, RN (b. unk – d. unk)

Specimens of Lichens and mosses from Newfoundland (1826). Although not individually itemised, it is likely that these were sold as part of Lot no. 2 'Sundry parcels of *Lichens, Mosses and other miscellaneous plants* – 10' (1856) purchased by Ingall. This is likely to be Thomas Ingall (c. 1799-1862) whose plant collection was donated to Warwick Archaeological and Natural History Society and subsequently moved to K (Desmond 1994) (and likely then to the BM).

East India Company [The Honourable The Court of Directors of the East India Company]

'Herbarium of Plants from various parts of the Honourable Company's Possessions in the East Indies' (1826) were sold to Brown for the BM.

William Griffith (1810-1845)

'East Indies – a large set from Bootan [Bhutan]; forming part of Griffiths' [sic] collections, dispersed by the East India Company – 8 parcels' (1856) were purchased by Planchon for MPU

Richard Brinsley Hinds (1812-1846)

'California – collected by Hinds, and published in the Voyage of the Sulphur' (1856) (Lot 9) attracted no bidders. Hinds was appointed surgeon of the HMS Sulphur in 1835 and collected plants during the voyage. Hinds (1844: 182) mentions that some 2000 collections had been deposited in Bentham's herbarium (now at K, with the exception of Lindley's orchid collection (now also at K) and Sir William Hooker's fern collection (also at K)). The location of the auctioned specimens has yet to be discovered.

Richard Stonhewer Illingworth Esq. (b.unk – d.unk)

'A collection of dried plants, from Santa Fe de Bogota' (1826). It is likely that these were Lot 44 'Santa Fe de Bogota – collected by Goudot – 3 parcels' (1856) that were sold to Pamplin for Grisebach at GOET.

Charles Mackenzie (1788-1862)

'St Domingo [Dominican Republic] – collected by Mr. Charles Mackenzie, a good set' (1856). Sold to Pamplin for Grisebach at GOET.

Mr Mont. Martin (1801-1868)

'East Coast of Africa – collected between 6° and 8° S lat., by Mr. Mont. Martin' (1856). Likely to be Mr Robert Montgomery Martin who joined the HMS Leven in June 1823 (see John Forbes above). Lot purchased by Bentham and as yet untraced although may be in LD or G.

Captain William Edward Parry RN (1790-1855)

'Herbarium of Arctic Plants collected on the Coasts and adjacent Islands of the North-east part of North America, in the Voyage to the Polar Seas in the years 1821, 1822 and 1823' [Voyage to find a passage near the northwest end of Hudson Bay] (1824). This is likely to be part of Lot 3 of the auction catalogue 'East Coast of West Greenland, Hammerfest, Spitzbergen, Red River and Hudson's Bay – partly named – a small parcel'. Purchased by 'Simes' according the RHS's annotated copy of the catalogue and 'Symes' in Brown's catalogue. As yet untraced although perhaps this Lot is one of the 'small parcels' of Parry's Arctic plants in BM or CGE? Parry's collections from North America occur also in the University of Oxford's herbarium (OXF). 'Simes' or 'Symes' may be John Thomas Irvine Boswell Syme (1822-1888) whose herbarium is listed in Index Herbariorum (Holmgren *et al.*, 1990) as being in the BM and at the University of Manchester (MANCH).

William Edward Phillips Esq. Lieutenant Governor of Prince of Wales's Islands CMHA (1769-?1850)

'Herbarium of Plants collected at Prince of Wales's Island and the contiguous land of Sumatra' (1824). Lot purchased by Planchon of MPU.

John Reeves Esq. (1774-1856)

'China – a small collection, formed in the neighbourhood of Macao by John Reeves, Esq.' (1856). Lot purchased by Daubeny so may be in the herbaria of the University of Oxford (FHO/OXF), but are as yet untraced.

John Richardson MD (1787-1865)

'Herbarium of Plants collected in the Interior of the Northern parts of North America, during the Journey of Captain Franklin to and from the coasts of the Polar Seas, in the years 1819, 1820 and 1821' [Richardson was the doctor, naturalist and second in command of this, the 'Coppermine Expedition'] (1824). Lot purchased by Planchon of MPU.

Captain Edward Sabine, RA (1788-1883)

Here we have two separate donations: 'Herbarium of Arctic Plants collected at Melville Island, in 1819 and 1820' [Parry expedition in search of the Northwest Passage] (1824). Lot 4 is likely to have contained this collection 'Melville Island – a small parcel, extremely rare' (1856) and was sold to Pamplin, buyer for Grisebach of GOET.

'Herbarium of Arctic Plants collected in a Voyage to the North Cape, Spitzbergen, and East Greenland, in the year 1823' [voyage to take Geodetic measurements] (1824). This is likely to be part of Lot 3 of the auction catalogue 'East Coast of West Greenland, Hammerfest, Spitzbergen, Red River and Hudson's Bay – partly named – a small parcel'. Purchased by 'Simes' according Lindley's annotated copy of the catalogue and 'Symes' in Brown's catalogue (See Parry (above)).

Mr Webster (1793-1875)

'Staten Island and Montevideo – collected by Mr Webster [William Henry Bayley Webster] in the voyage of the Chanticleer' [scientific expedition in the Pacific Ocean under the command of Captain Henry Foster in 1828] (1856). Lot purchased by Planchon of MPU.

John Williams Esq. CMHS (b.unk – d.unk)

'A Collection of Specimens of Mosses and lichens from the Neighbourhood of Moose Factory, Hudson's Bay' (1826) This is likely to be part of Lot 3 of the auction catalogue 'East Coast of West Greenland, Hammerfest, Spitzbergen, Red River and Hudson's Bay – partly named – a small parcel'. Purchased by 'Simes' according Lindley's annotated copy of the catalogue and 'Symes' in Brown's catalogue (See Parry and Sabine (above)).

Henry Willock Esq, FHS (1790-1858)

'Specimens of Dried roses, from Persia' (1826). 'Persia – a set of specimens, from Tabreez, and formed during a journey to Tiflis through Armenis to Trebizond ©, glued upon fine paper (1856). This lot was purchased by 'Hooker' for K. A thorough search of the collection has failed to locate any Willock specimens.

Miscellaneous collections

The catalogue lists a smaller number of Lots that have been divided into specimens from specific countries or regions. In the case of Lot 43 it is possible to deduce the collector/donor of what appears to be duplicates.

Lot 1: a miscellaneous collection, from Switzerland, named; the Southern States of N. America; and New Holland – 3 parcels (1856). Lot sold to Papillon. As suggested above this might be a *nom de plume* for JC Stevens (his brother was a keen butterfly collector), buying on behalf of John Lindley.

Lot 6: four miscellaneous Parcels (1856). Lot sold to Pamplin, buyer for Grisebach of GOET

Lot 43. Miscellaneous duplicates, Cape of Good Hope, Delagoa Bay, Sandwich Islands and Chili (1856). It is likely that the African collections were duplicates of Forbes collections and the Sandwich Island and Chilean collections were MacRae duplicates. Lot sold to Pamplin, buyer for Grisebach of GOET.

Lots, buyers and their eventual herbairum

Auction catalogue break-down of Lots and their buyers. Content is as presented and spelt in the catalogue. Where buyer and price annotation differences between the two catalogues occur, they are noted below with either BM for Brown's catalogue or RHS for Lindley's catalogue. On the first page of Brown's (BM) catalogue is a handwritten note mentioning Bentham as the agent acting on behalf of Agardh and De Candolle. More details about the herbaria can be found in the paragraphs above.

Lot	Content	Buyer	Price paid (£sd)	herbarium
1	A miscellaneous collection, from Switzerland, named; the Southern States of N. America; and New Holland – 3 parcels	Papillon (RHS)	0 10 0	?CGE
2	Sundry parcels of Lichens, Mosses and other miscellaneous plants – 10	Ingall (RHS)	3 3 0	?BM
3	East Coast of West Greenland, Hammerfest, Spitz-Bergen, Red River and Hudson's Bay – partly named – a small parcel	Simes (RHS) Syme (BM)	1 0 0	?BM/? MANCH
4	Melville Island – a small parcel, extremely rare	Pamplin [Pamplin for Gourlu [?] (BM)]	1 6 0	GOET
5	Arctic America – collected by Sir John Richardson, named	Planchon	2 16 0	MPU
6	Four miscellaneous parcels	Pamplin	0 10 0	GOET

Lot	Content	Buyer	Price paid (£sd)	herbarium
7	North-West America and California – collected by Douglas. All glued down on fine paper, and for the most part named. From these plants, in part, the Flora Boreali-Americana of Sir William Hooker was drawn up. The number of species is about 500 – 15 parcels	Brown [BM with later catalogue note '1460 species besides duplicates fide J.J.Bennett']	32 0 0	BM
8	California – Hartweg's collection	Bentham	9 10 0	LD
9	California – collected by Hinds, and published in the Voyage of the Sulphur	No bidder	0 0 0 (RHS) 1 0 0 (BM)	
10	Mexico – Hartweg's collection; this fine set is the original from which Mr Bentham's Plantae Hartwegianae were described, all slightly glued on fine paper – 12 parcels	Bentham	11 0 0	LD
11	Mexico – Botteri's plants – found on Orizaba; good specimens, loose, about 1000 species – 9 parcels	Planchon	28 0 0	MPU
12	United States – the plants gathered by Douglas on his first visit to N. America – 10 parcels	No Bidder	0 0 0 (RHS) 1 0 0 (BM)	
13	Sandwich Islands – Macrae's collection – 4 parcels	Brown	9 0 0	BM
14	Staten Island and Montevideo-collected by Mr Webster in the voyage of the Chanticleer	Planchon	0 15 0	MPU
15	Trinidad – collected by George Don – 8 parcels	Bentham	4 0 0	?LD & ?G
16	Jamaica – ditto – 2 parcels	Roberts (RHS)	1 12 0	
17	Grand Cayman – ditto	Roberts (RHS)	0 0 0 (RHS) 1 0 0 (BM)	
18	Ascension – ditto	Pamplin (RHS) Pamplin for Grisebach (BM)	0 16 0	GOET
19	Havannah – ditto	Pamplin (RHS) Pamplin for Grisebach (BM)	0 10 0	GOET
20	St. Domingo – collected by Mr. Charles Mackenzie, a good set	Pamplin (RHS) Pamplin for Grisebach (BM)	1 0 0	GOET
21	Brazil – collected by Macrae, in the neighbourhood of Rio Janeiro and St. Catherine's – 5 parcels	Pamplin	2 0 0	GOET
22	Brazil – collected by Forbes, near Rio Janeiro – 9 parcels	J. Sowerby	1 0 0 (RHS) 1 1 0 (BM)	BM
23	Brazil – collected at Maranhão, by George Don – 6 parcels	Bentham	2 15 0	?BR
24	Brazil – collected at Bahia, by George Don – 4 parcels	Bentham (RHS)	0 0 0	?BR
25	Brazil – collected near Rio Janeiro, by Douglas – 2 parcels	Pamplin	1 0 0 (RHS) 1 1 0 (BM)	GOET
26	Chili – a fine set, from Macrae – 5 parcels	Planchon	9 0 0	MPU

Lot	Content	Buyer	Price paid (£sd)	herbarium
27	Chili and Brazil – sundry duplicates, collected by Macrae – 2 parcels	Planchon	0 19 0	MPU
28	Chili – collected on Juan Fernandez, by Douglas	Bentham	2 0 0	?LD & ?G
29	East Indies – a fine set of plants, named, dried by Potts in the Botanic Gardens, Calcutta – 9 parcels	J. Sowerby	1 1 0	BM
30	East Indies – a large collection, named; distributed by the East India Company – 12 parcels	Brown	3 0 0	BM
31	East Indies – a large set, from Bootan; forming part of the Griffiths' collections, dispersed by the East India Company – 8 parcels	Planchon	11 10 0	MPU
32	China – Fortune's plants, from Hong Kong, Chusan and other places	Planchon	9 5 0	MPU
33	China – a small collection, formed in the neighbourhood of Macao, by John Reeves, Esq.	Daubeney (RHS) Daubeny (BM)	1 5 0	OXF
34	China – collected by Parkes, 17 parcels, 4 of which are marked as duplicates	Bentham	4 10 0	?LD & ?G
35	China – collected by Potts	Daubeney (RHS) Daubeny (BM)	1 1 0	OXF
36	China – a small parcel of specimens of the Tea plant collected by Fortune	Papillon (RHS)	0 11 0	CGE
37	Ceylon – collected by Macrae. An extensive collection, in large sized cartridge paper, not named or glued down – 9 parcels	Brown	21 0 0	BM
38	Java – a small collection formed by Parkes	No bidder	0 10 0 (BM)	
39	Prince of Wales' Island – sent home by Governor Phillips. A very considerable collection, arranged in natural orders, and to a great extent named – 14 parcels	Planchon	25 0 0	MPU
40	Cape of Good Hope – collected by Forbes, a fine set of plants – 3 parcels	Planchon (RHS)	0 0 0 (RHS) 1 0 0 (BM)	MPU
41	Delagoa Bay – collected by Forbes, another fine set – 3 parcels	Planchon	9 0 0	MPU
42	Algoa Bay – collected by Forbes – 3 parcels	Brown	5 0 0	BM
43	Miscellaneous duplicates, Cape of Good Hope, Delagoa Bay, Sandwich Islands and Chili	Pamplin	1 0 0 (RHS) 1 1 0 (BM)	GOET
44	Santa Fé de Bogota – collected by Goudot – 3 parcels	Pamplin (RHS) Pamplin for Grisebach (BM)	3 10 0	GOET
45	St Helena – collected by Macrae	Pamplin	1 0 0	GOET
46	East Coast of Africa – collected by Forbes	Bentham	5 0 0	?LD & ?G
47	East Coast of Africa – collected between 6° and 8° S. lat. By Mr Mont Martin	Bentham	1 1 0	?LD & ?G
48	Madagascar – collected by Forbes	Brown	2 10 0	BM

Lot	Content	Buyer	Price paid (£sd)	herbarium
48*	New Holland – collected by James Brogden, Esq. – 2 parcels	Brown (RHS)	0 0 0 (RHS) 1 0 0 (BM)	BM
49	Persia – a set of specimens, from Tabreez, & formed during a journey to Tiflis through Armenia to Trebizond, glued upon fine paper	Dr Hooker	1 10 0	?K
49*	Cape de Verd – collected by G. Don, at St. Jago	Dr Hooker (RHS)	0 0 0 (RHS) 1 0 0 (BM)	?K
50	Madeira and Teneriffe – collected by Forbes – 2 parcels	Money (RHS)	1 1 0	
50*	Cape de Verd, St. Vincent	Money (RHS)	0 12 0	
51	Cape de Verd, St. Vincent – collected by Forbes, at St. Jago		0 0 0 (RHS) 0 18 0 (BM)	
52	Madeira – collected by George Don	Pamplin	0 14 0	GOET
53	Teneriffe – collected by George Don – 2 parcels	Pamplin (RHS) Pamplin for Grisebach (BM)	0 18 0	GOET
54	West Coast of Africa – George Don – 9 parcels. This collection is named by the authors of the Niger Flora, and may be regarded as typical of that work	Brown (RHS) Brown (BM with later catalogue note 'contained 700 species'	12 10 0	BM
		Total (RHS)	249 12 0	

Conclusion

Having scrutinised the two catalogues, and followed a variety of trails, a large proportion of the original RHS herbarium has been located so it will be possible to view the Horticultural Society of London's auctioned specimens when the collections have been fully digitised and made available online.

The bulk of the collection is to be found in the herbarium of the Natural History Museum in London, and also in the herbaria of Paris and Montpellier. However, defeat has to be admitted in tracking down a number of collections and also verifying the location of others. With the exception of the Hartweg collections housed in LD, it is still a challenge to find specimens within herbaria whose collections may have just been, or are presently undergoing digitisation.

Of immense value has been being able to view digitally some of the older duplicates, with labels or stamps showing their original owners before being moved to another, larger herbarium. It is tantalising to have access to one of the greatest compilation of specimens in the World available on the GBIF site, but without a chance of searching by collector, some of our plant collectors' specimens remain unfindable at present. Similarly that some of the online herbaria have not yet managed to transcribe all collections so their collectors remain 'silent' as far as a search goes.

When the CGE team are able to fully digitise the Lindley collection it is likely to prove to be the catalyst that leads to the tracking down of the unknown herbaria of the auctioned collection. This resource will provide the plant names necessary for a number of search engines. Is it possible to dream that the unsold Lots were cared for by Lindley and passed to CGE (with his herbarium) in 1866?

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29. Went to Cox's, Clowes', Prior's and Well's, cut up wood and drew some letters. No news. Parliament meets on Thursday. They are getting on with the Houses of Parliament very rapidly, in anticipation of it. A peace conference is going to meet in Paris in the beginning of next month. Murders are plentiful about this time of year; there have been several fresh ones lately. Very cold and dry.

Effectiveness of ambient control on invertebrate pest management in a botanical collection in the Galapagos

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Abstract

Herbaria are natural history collections that host a vast amount of information on plant taxonomy, biology, distribution, and genetic diversity, and are therefore are a key resource for scientific research. However, changes in environmental conditions can make these collections highly susceptible to pest infestations. Maintaining relative humidity (RH) and temperature control within herbaria can help preserve plant specimens. The role of these variables has not been properly studied in tropical regions, especially in relation to the abundance of invertebrates that can infest collections. In this study we use daily temperature and RH measurements, and data from invertebrate pest traps collected quarterly between 2017-2021 in the CDS herbarium of the Charles Darwin Research Station. With these data, we test for 1) the effect of ambient conditions on invertebrate abundance in the herbarium, 2) the effect of surpassing the recommended temperature and RH thresholds on invertebrate abundance, and 3) the correlation between herbarium ambient conditions and outdoor weather data, in order to evaluate the effectiveness of environmental controls. Our results show a significant positive correlation between periods of high temperature and the abundance of invertebrates, increasing the number of individuals by 32.4% per 1°C (±12.7 S.E., p = 0.02), but no significant effects on potential pests. We also found a significant correlation between outdoor and indoor environmental conditions. These results suggest that despite imperfect environmental controls, best practice recommendations of 40-55% humidity and temperature of 21-23°C are most appropriate for maintaining invertebrate pest control. In this case, work is needed to ensure temperature is maintained below 23°C to prevent growth and spread of invertebrates in collections. Altogether, this study shows the direct relationship between environmental conditions and the abundance of invertebrates, and stresses the importance of maintaining ambient control in natural history collections in tropical climactic regions.

Keywords: Herbaria; environmental control; invertebrates; pest management; temperature; humidity; IPM

Introduction

Natural history collections such as herbaria are essential for hosting the biological and genetic resources necessary for botanical research (e.g., studies in morphology, taxonomy, genetics), environmental monitoring, and scientific education (Suarez and Tsutsui, 2004; Bradley *et al.*, 2014).

Being such an important tool and resource, collections need to be curated and preserved correctly to ensure their long-term preservation and use (Fosberg, 1946; Giberti, 1998). Among the biggest threats to herbarium collections are pests, particularly invertebrates, due to the damage they can cause to a collection (Bridson and Forman, 1998; Guarino *et al*, 2019). The CDS herbarium in the Charles Darwin Research Station in the Galapagos Islands is the only herbarium on the archipelago. It is the most significant collection of botanical specimens from the Galapagos Islands (Jaramillo *et al.*, 2020; Mauchamp and Aldaz, 1997) containing approximately 46k specimens of plants and fungi found in the Galapagos (CDF Collections dataZone, 2021). The CDS has played a pivotal role in botanical research for Ecuador and the Galapagos Islands over the past few decades. The main collection of vascular plants and ancillary collections of pollen and seeds has supported projects on plant-animal interactions (Blake *et al.*, 2012; Traveset *et al.*, 2015), palynology (Van Leeuwen *et al.*, 2008), Galapagos plant taxonomy (Darwin *et al.,* 2003; Weeks and Tye, 2009), species descriptions and identification guides (Bungartz *et al.,* 2020; Jaramillo *et al.*, 2021), and ecological restoration and urban restoration (Atkinson *et al.*, 2017; Tapia *et al.*, 2019).

Historically, methods to protect herbarium collections from infestations have included chemical pest control by fumigation, or 'protecting' specimens with pesticides (Querner *et al.,* 2013; Thacker, 2002). These methods, however, are often costly and toxic for users (Hall, 1988; Drobnik, 2008), and leave chemical residue on the specimens. This has caused certain agents to be made illegal (for example, ethylene oxide and carbon disulphide) due to health and safety concerns (Pinniger and Harmon, 1999; Querner *et al.,* 2013). It is for this reason that successful integrated pest management programs (IPM) focus mostly on prevention and monitoring, with pest control and treatment being only one part of the process (Querner *et al.*, 2013; Querner 2015). Alternative solutions such as those implemented in the CDS herbarium focus on preventative actions, such as controlling the environmental factors in collection storage that promote pest growth; establishing strict quarantine and sterile entry procedures for incoming specimens; and ensuring proper sealing of both entrances to collections and of containers and cabinets. These have been suggested to be just as effective while being much safer for use in an environment where students and staff routinely work (Croat, 1978; Querner *et al.*, 2013; Rojas *et al.,* 2020).

The most conservative environmental conditions recommended for preventing pest infestations in botanical collections are a stable relative humidity (RH) ranging between 30% and 55% and temperatures of 20-23°C (Dawson, 1987; Bridson and Forman, 1998; Szczepanowska *et al.,* 2013; Kirby-Atkinson, 2014). These limits are recommended to avoid the growth of mould, damage to binding glue, and discourage the presence of invertebrate pests (Rose and Hawks, 1995; Simmons and Muñoz-Saba, 2003; Giberti, 1998; Rojas *et al.,* 2020). Maintaining low humidity and a clean environment prevents the proliferation of dust and organic matter which helps inhibit the presence of paper-damaging pests (Querner, 2015), and maintaining RH below 43% in herbaria is recommended to inhibit growth of insect pests that damage herbarium specimens (Hall, 1988). These environmental conditions can be implemented with the use of air-conditioning units or heaters, and humidifiers or dehumidifiers, depending on the local climate (Linnie, 1996; Strang, 1997; Rojas *et al.*, 2020). For example, a review by Kirby-Atkinson (2014) discusses how temperature and humidity ranges in a collection can be adjusted depending on local climate together with an institution's financial or carbon budget. The environmental conditions required for herbaria therefore need to be evaluated on a case-by-case basis, and while collections in temperate regions may be able to limit their use of air conditioning units and humidity regulators, tropical herbaria might not have this same flexibility (Rojas *et al.,* 2020).

Botanical collections in tropical regions are especially vulnerable to infestations due to the naturally higher temperature and relative humidity which encourage biological activity of invertebrate pests (Croat, 1978; Bridson and Forman, 1998; Jaramillo *et al.*, 2005). Pests such as *Stegobium paniceum* (Linnaeus, 1758) and *Lasioderma serricorne* (Fabricius, 1792) develop faster at high temperatures (~30°C) and *Liposcelis* spp., silverfish, and cockroaches thrive at humidity levels above 60% (Pinniger and Harmon, 1999). In 2017, there was an infestation of *L. serricorne* (cigarette beetle) in the CDS herbarium which caused damage to approximately 18,000 specimens of 14 vascular plant families (Acurio *et al.,* 2018). A procedure involving pest control, fumigation, quarantine, and posterior cleaning of specimens was implemented after the incident. Following this, a pest management protocol was implemented, and the current study uses data collected since then to test its efficacy.

In temperate regions, insects do not survive outside heated areas all year round and infestation is therefore a less frequent problem (Kirby-Atkinson, 2014; Inuzuka, 2016). Most studies on the effects of environmental conditions in collections have been conducted in temperate regions (such as the UK, Western Europe or the US). This could suggest that these temperature and relative humidity best-practices might not be feasible for collections in other climates such as tropical or subtropical regions (Bickersteth, 2014; Kirby-Atkinson, 2014; Staniforth, 2014; Inuzuka, 2016). Multiple previous studies in agriculture have linked the effects of temperature and humidity to reproduction, growth, and development of invertebrate pests (Chang *et al.,* 2008; Norhisham *et al.,* 2013; Zulfiqar *et al.,* 2010). These studies suggest that surpassing certain levels of maximum temperature or relative humidity in a closed environment such as our herbarium could stimulate invertebrate growth. Studying the association between these environmental factors and invertebrate abundance is critical in helping determine ideal environmental control best-practices for tropical herbaria.

In this study we use four years of invertebrate and environmental data from the Charles Darwin Station Herbarium (CDS) in the Galapagos Islands (Ecuador) to test the association of environmental variables with invertebrate abundance. Specifically, our objectives were to:

1. test for any association of maximum temperature and/or maximum RH with the abundance of invertebrates and pests found inside the collections;

2. evaluate the effect of exceeding the current recommended environmental thresholds on the presence or abundance of pests, and

3. test the effect of the local climate on the temperature and humidity within the herbarium to evaluate the efficacy of environmental controls in a tropical herbarium.

Through these objectives we aim to find empirical recommendations for the IPM of tropical herbaria. Herbaria in the tropics face greater challenges in terms of invertebrate pest control due to natural climate differences (Jaramillo *et al.*, 2005), and this assessment of current pest management and control will serve as a guide and reference for the conservation of natural history collections in similar regions.

Methods

Location

The study took place in the CDS herbarium (henceforth CDS), one of four natural history collections of the Galapagos National Park, located in Charles Darwin Research Station (CDRS) in the Galapagos Islands, Ecuador (0°44'32.4"S 90° 18'13.4" W). Being the only botanical collection in the Galapagos Islands and the main point of reference for botanical studies, it is crucial that appropriate integrated pest management methods are employed to ensure long-term preservation of the collections. Controlling entry to the collections helps maintain and prevent accidental damage to collections (Rojas*,* 2011). Access to the collections is limited to research and scientific purposes only, and scientists may only access the collection with a research permit (Jaramillo *et al.,* 2013). This protects specimens from damage and reduces the risk of pests entering the collections, which could occur due to the herbarium's location right inside the Galapagos National Park.

Ambient control

Air conditioning units and dehumidifiers are used to maintain control of temperature and relative humidity on a 24-hour basis, and thermohygrometers are used to measure ambient temperature (°C) and relative humidity (%). Temperature and humidity levels were measured by taking readings every 24h from two BOE 330 thermohygrometers. The herbarium is of 75m^2 and is divided in two equally-sized areas, so each thermohygrometer was placed in the centre of each herbarium room. This daily monitoring informs of the atmospheric conditions within the herbarium environment to ensure they remain approximately between 20-23°C with a conservative maximum of 50% relative humidity. These controls are based on conservative guidelines from the literature as it is difficult to ensure constant environmental conditions throughout the rooms. Since 1995, air conditioners and dehumidifiers were installed in the collections with the purpose of maintaining atmospheric control (Jaramillo, 2002; Jaramillo and Tye, 2003). To do this there are currently two air conditioners and three dehumidifiers in place, set to 21°C and a maximum RH of 50% respectively. During this study, temperature and relative humidity data recorded in both collection rooms was analyzed for the period between 2017 and 2021.

Herbarium infrastructure

The CDS follows strict freezing and drying protocols for all specimens before entry into the collections. Botanical specimens are placed in a heated chamber (light-bulb dryer) to dry any living materials (as suggested by Strang, 1995), and frozen at -18°C for at least 48h to kill any living organisms. Plant specimens, after being identified and mounted on herbarium sheets, are stored in sealed metal cabinets which protect plant material from dust, mechanical damage, light and also reduce the entry of invertebrate pests (Bridson and Forman, 1998). These herbarium cabinets are not completely sealed and also allow the passage of air, which assumes specimens are stored in similar atmospheric conditions as the rest of the collection room. The herbarium was built in 1994, and air conditioners were installed for temperature and humidity control in 1995 (Jaramillo and Tye, 2003). The collection room has since undergone some structural improvements such as permanent sealing of windows and other potential pest entry points, and, in 2017, was expanded to fit a growing collection. However, the foundations of the building are still several decades old, and there have been problems with water leaking into the collections during the rainy season.

Pest prevention and control

Through the IPM plan, CDS employs several measures of control. Physical control includes the use of metal cabinets mentioned earlier, as well as airtight containers, envelopes, and boxes to prevent the entry and spread of invertebrate pests in and around botanical specimens. There is also a room for quarantining specimens, where collected plants are frozen and kept for a week before they enter the main collection room to be identified. Chemical control in the herbarium includes an annual fumigation procedure using the insecticide Raid ® Multi, which contains fewer chemical agents than traditional insecticides, and is executed by the maintenance team for further pest prevention (Jaramillo *et al.,* 2013; Jaramillo *et al.,* 2020). The main method for monitoring and controlling invertebrate pests is the use of sticky traps, placed along wall skirtings, in corners and entry points of the collection where crawling invertebrates are likely to be found (Querner *et al.,* 2013; Windsor *et al.,* 2015; El-Hassan *et al.,* 2021). Pre-baited and non-poisonous sticky (blunder) traps ("Catchmaster 150MBGL Gluee Louee" brand) are used to attract and trap crawling invertebrates. Periodic identification of trapped organisms and replacement of traps allows for early detection of pests.

Invertebrate identification

As part of the IPM program (Jaramillo *et al*., 2020), the blunder traps were collected every 3 or 6 months from 2017 until 2021, and once between 2019 and 2020 due to staffing issues and climactic conditions (these time period differences are accounted for in the analysis). Invertebrates caught in each trap were identified to the lowest possible taxonomic level with assistance from the entomological team from the Terrestrial Invertebrate Collection of the Charles Darwin Research Station (ICCDRS). Organisms that could not be identified to species level were labelled as "*Incertae sedis"* along with the lowest possible taxonomic level of identification. A list of all invertebrates in taxonomic order is provided in Table 1. Species that are known to be pests, or individuals identified to order or family level of groups known to be herbarium pests, were tagged as "potential pests" for further analysis (based on Iverson *et al.* 1996; Hall, 1988, Pinniger and Harmon, 1999; Sun and Zhou, 2012; Alexander *et al*., 2015; GISD, 2015 and Pocklington, 2015).

Data analysis

Environmental data in the collections from the years 2017-2021 were compared to the invertebrates trapped in those years. Mean and maximum values of temperature and relative humidity (RH) were calculated for each monitoring period based on daily morning measurements (Supplementary Table 1). These data were used to assess the relationship between ambient conditions (using maximum values of temperature and humidity) and invertebrate presence while the mean values were modelled against the outdoor environmental data. Due to the difference lengths of monitoring periods, the total number of days between each monitoring event was accounted for in all models. Two random effects were also included in the model: invertebrate order accounts for differences in diversity between invertebrate taxonomic groups, and unique trap ID accounts for the non-independence of samples collected from the same trap. The R package *lme4* (Bates *et al.,* 2015) within RStudio v.1.0.136 (R Core Team, 2021) was used to fit generalized linear Poisson models (GLM) with invertebrate number as the dependent or response variable, and temperature and RH as effect variables, as well as length of monitoring period and the additional random effects. A table with the explanation of the models used to test each hypothesis explains the fixed and random effect variables in each model (Supplementary Table 2).

For objective 1 (testing association between invertebrate abundance and temperature or RH), *P*-values were obtained by performing likelihood ratio tests (LRT) of the full model with the effect in question (maximum temperature and RH) against models without each of those effects.

The same tests were also performed using a dataset of only potential pest taxa. Poisson coefficients from the full model of the effect of temperature and RH were converted to proportional effects on the response variable by exponentiating and subtracting one. Marginal effect plots using fixed effect errors were also plotted using the *ggeffects* package (Lüdecke, 2018) to visualize the predicted effects of temperature and humidity on insect abundance while keeping all other variables constant. For objective 2, the efficacy of recommended limits was tested using the conservative thresholds of 24°C and 50% RH. The number of days within a single monitoring period in which these thresholds were surpassed was modelled against invertebrate and pest abundance using the GLM described above. For objective 3, the mean daily air temperature and RH was compiled from weather data and compared to the ambient temperature and RH collected daily in the CDS herbarium for the years 2017-2021. Weather data from Puerto Ayora, the town in which CDS is located, was downloaded from the Charles Darwin Foundation dataZone website (https://www.darwinfoundation.org/en/datazone/climate/puerto-ayora). To test for an association, a correlation test using the Pearson method was computed for both temperature and RH. The R package *ggplot2* within *ggpubr* (Alboukadel, 2020) was used to produce a scatterplot with the correlation results.

Results

Effect of temperature and humidity on invertebrate abundance

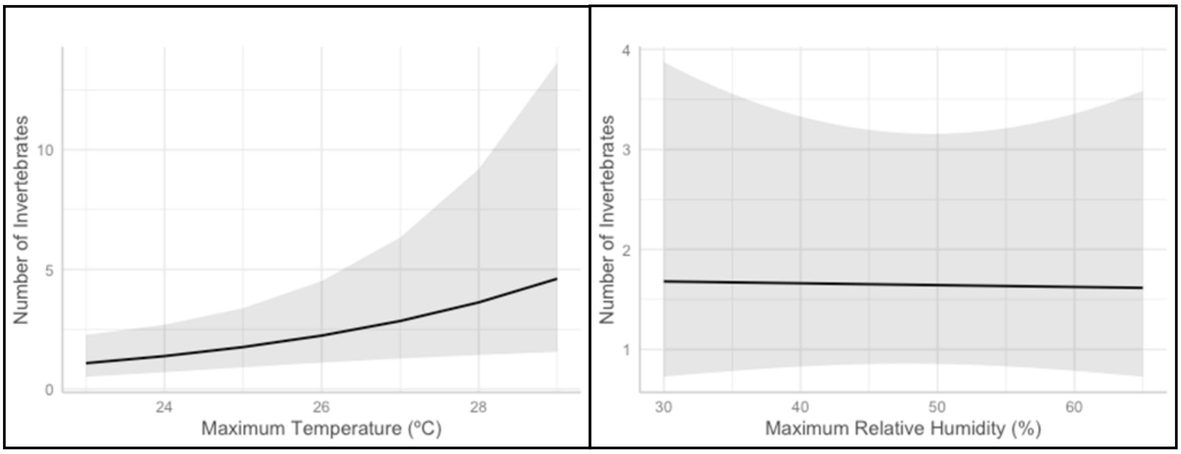
We found that although humidity does not significantly affect the abundance of invertebrates found in the herbarium ($\chi 2$ (1) =0.0054, p=0.94), temperature does ($\chi 2$ (1) =5.3193, p=0.02), increasing the number of individual invertebrates by 32.4% ± 12.7 S.E. per °C (Figures 1A and B). When focusing the analysis only on the potential pest species (Table 1), we found that neither temperature nor humidity had a significant effect on pest abundance.

Effect of exceeding the temperature or humidity threshold on the abundance of invertebrates

Neither the number of days on which temperature was over 24°C ($\chi 2$ (1) =0.8967, p=N.S.) or the number of days on which humidity was greater than 50% ($\chi 2$ (1) = 0.0087, p=N.S.) in a single monitoring period was significantly associated with the number of invertebrates found during that monitoring period. This was also tested using the dataset of only pest species, and there was no significant association between the variables of temperature ($\chi 2$ (1) =2.529, p=N.S.) or humidity ($\chi 2$ (1) =1.4685, p=N.S.).

Correlation between outside climate and internal herbarium environment

We found a significant correlation between average outdoor and indoor temperature (cor=0.355, $p < 0.001$) and average outdoor and indoor humidity (cor=0.258, p-value < 0.001) (Figures 2 and 3).



Figures 1A and B. Lineplot with confidence band showing the relationships between maximum values of temperature in °C per monitoring period (1A) and % relative humidity (1B) with number of invertebrates found in the CDS collections. Temperature had a positive significant effect on the number of invertebrates present in the collections (p = 0.02), while RH did not have any significant effect.

Table 1. Invertebrate species by taxonomic level and total number of individuals of each species collected per blunder trap, per monitoring event; as well as whether it has been cited as being a pest (based on Iverson et al. 1996; Hall, 1988, Pinniger and Harmon, 1999; Sun and Zhou, 2012; Alexander et al., 2015; GISD, 2015 and Pocklington, 2015).

Order	***Family***	***Species***	***Pest potential***	***Number of individuals***
Acari	NA	*Acari incertae sedis*	Yes	11
	Linyphiidae	*Linyphiidae incertae sedis*	Unknown	10
	NA	*Araneae incertae sedis*	Unlikely	6
	Oecobiidae	*Oecobius concinnus* (Simon, 1893)	Unkown	2
	Oonopidae	*Gamasomorpha sp.*	Unkown	22
	Pholcidae	*Aymaria conica*	Unlikely	31
		Modisimus sp.	Unknown	4
		Physocyclus globosus (Taczanowski, 1874)	Unknown	16
	Selenopidae	*Selenops galapagoensis* (Banks, 1902)	Unknown	3
	Blaberidae	*Psycnoscelus surinamensis (*Linnaeus, 1758)	Yes	27
	Blattellidae	*Symploce pallens* (Stephens, 1835)	Yes	1
	Blattidae	*Blattidae incertae sedis*	Yes	1
		Periplaneta americana (Linnaeus, 1758)	Yes	3
		Periplaneta australasiae (Fabricius, 1775)	Yes	7
		Periplaneta sp.	Yes	3
	NA	*Blattodea incertae sedis*	Yes	5
	Polyphagidae	*Holocompsa nitidula (*Fabricius, 1781)	Yes	3
	Carabidae	*Calosoma granatense* (Géhin, 1885)	Unknown	2
	Curculionidae	*Xyleborus spinulosus* (Blandford, 1898)	Unknown	1
	Elateridae	*Dipropus puberulus* (Boheman, 1858)	Unknown	1
	Phalacridae	*Phalacrus darwini* (Waterhouse, 1877)	Yes	2
	Ptinidae	*Lasioderma serricorne* (Fabricius, 1792)	Yes	7
	Tenebrionidae	*Blapstinus sp.*	Unlikely	2
Collembola	NA	*Collembola incertae sedis*	Yes	21
Diptera	Culicidae	*Aedes taeniorhynchus* (Wiedemann, 1821)	Unlikely	3
	Phoridae	*Dohrniphora cornuta* (Bigot, 1857)	Unknown	1
		*Megaselia scalaris (*Loew, 1866)	Yes	2
		Megaselia sp.	Yes	57
	Psychodinae	*Clogmia sp.*	Unknown	3
		Psychodinae incertae sedis	Unknown	1
	Sarcophagidae	*Sarcophagidae incertae sedis*	Unknown	1
	Sciaridae	*Sciara sp.*	Yes	3

Table 1. ***(cont)***

Order	***Family***	***Species***	***Pest potential***	***Number of individuals***
Hymenoptera	Diapriidae	*Diapriidae incertae sedis*	Unknown	6
	Formicidae	*Camponotus conspicuus zonatus* (Emery, 1894)	Unlikely	37
		Camponotus sp.	Unlikely	2
		Monomorium floricola (Jerdon, 1851)	Yes	16
		Odontomachus bauri (Emery, 1892)	Possibly	1
		Tapinoma melanocephalum (Fabricius, 1793)	Yes	21
		Tetramorium bicarinatum (Nylander, 1846)	Unknown	1
Isopoda	Porcellionidae	*Metoponorthus pruinosus* (Brandt, 1833)	Unknown	3
		Porcellio laevis (Latreille, 1804)	Yes	1
		Porcellionides pruinosus (Brandt, 1833)	Yes	544
Lepidoptera	Geometridae	*Cyclophora impudens* (Warren, 1904)	Yes	1
N/A	NA	*Incertae sedis 2*	Uknown	2
Ortoptera	Gryllidae	*Cycloptilum erraticum* (Peck, 1996)	Unknown	6
		Cycloptilum sp.	Unknown	3
		Gryllus sp.	Unknown	13
Psocoptera	Epipsocidae	*Epipsocus sp*	Yes	2
	Lachesillidae	*Lachesilla sp.*	Yes	63
	Lepidopsocidae	*Lepidopsocidae incertae sedis*	Yes	9
	Liposcelididae	*Liposcelididae incertae sedis*	Yes	42
		Liposcelis entomophila (Enderlein, 1907)	Yes	15
	NA	*Psocoptera incertae sedis*	Yes	1
Scolopendromorpha	Scolopendridae	*Scolopendra galapagoensis* (Bollman, 1889)	Unknown	1
Solifugae	Ammotrechidae	*Neocleobis solitarius* (Banks, 1902)	Unknown	4

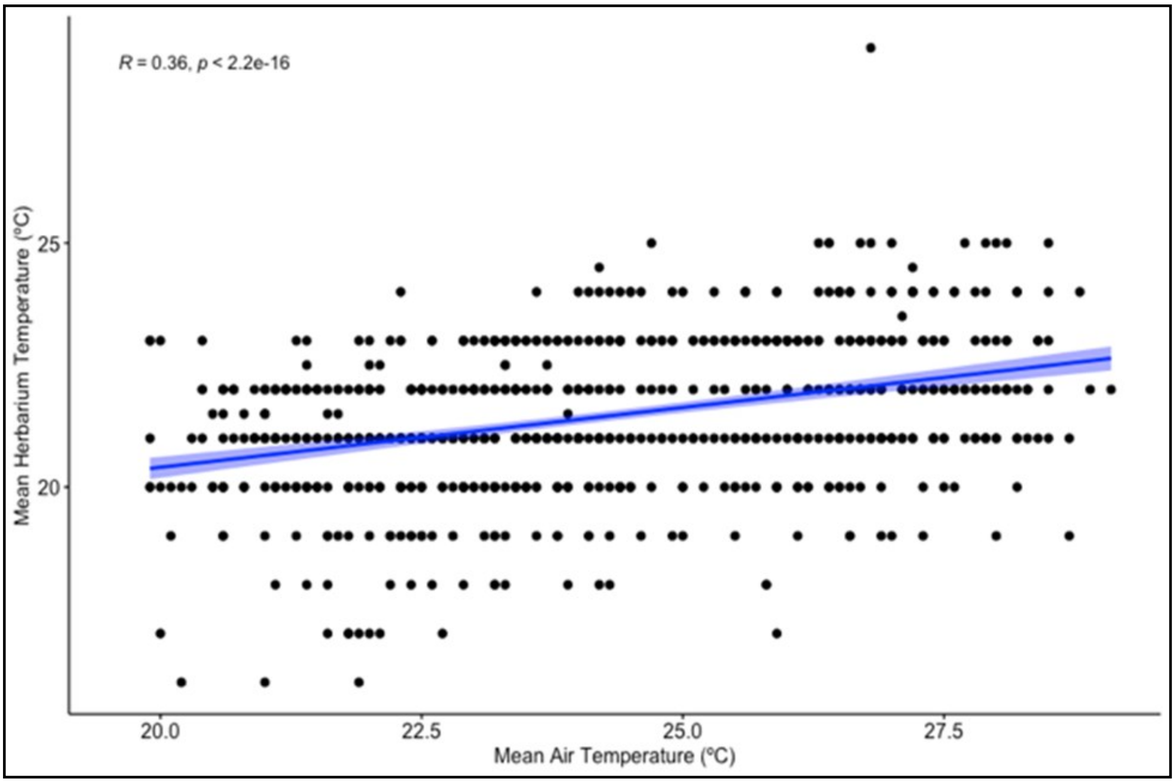


Figure 2. Scatterplot of the correlation between mean temperature (°C) inside and outside the CDS.

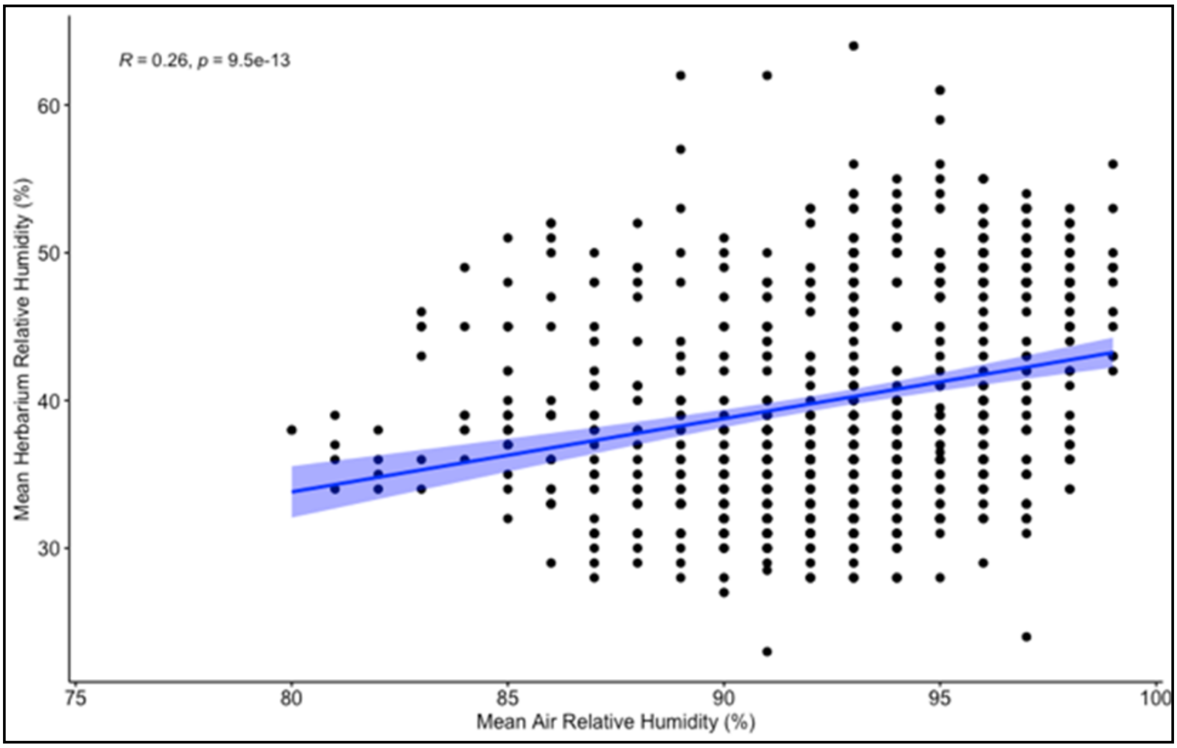


Figure 3. Scatterplot of the correlation between mean relative humidity (%) in and outside the CDS.

Discussion

To summarise the main results, firstly, maximum temperature values (per monitoring period) had an effect on the number of invertebrates found in the collection (32% increase for each 1°C) but not significantly on those that are pests, while maximum RH conditions did not have an influence. Secondly, the number of days in which temperature and RH exceeded the recommended thresholds did not significantly affect the presence or abundance of invertebrates (nor pests) found in the collections during that time. And, thirdly, there was a small but significant correlation between outdoor and indoor herbarium environments, with temperature being slightly more closely correlated.

While indoor humidity levels did not significantly influence herbarium invertebrates, temperature did, which is concerning as indoor and outdoor temperature were also more correlated to one another. This may suggest an indirect impact of outdoor temperature on herbarium invertebrates, which highlights the need for tighter temperature control or more protective infrastructure. This result, however, could also be explained by the fact that during the period of study, the maximum levels of RH (on average 49%) were also well within average recommended humidity levels (40-55%), while maximum temperatures averaged 25°C, above the 20-23°C suggested margin (Supplementary Table 1). Humidity-loving pests present in our traps such as *Clogmia* sp., individuals of the taxonomic group Collembola (springtails) which feed on mould and dry plant matter (Hopkin and Stephen, 1997) and cockroaches such as *Psynoscelis surinamensis, Holocompsa nitidula* and both *Periplaneta* species thrive at high humidities present in tropical countries (Pinniger and Harmon, 1999; Notton, 2018; El-Hassan *et al.*, 2021). Species of Psocoptera (book lice) were found in nearly all monitoring events, and albeit in low numbers, these can become a problem if ambient conditions are not controlled, as they thrive under humid conditions of 60% RH and above. These insects are known to feed on mould and starch as well as paper and even plant specimens (Querner, 2015; Notton, 2018). While these invertebrates were identified among our trap data, analyses of pest data showed that their numbers were not significantly correlated with humidity levels in the herbarium. The current use of three dehumidifiers plus two air conditioning units in the herbarium may, then, be sufficient to provide optimal relative humidity levels in the collections and prevent population growth of these pests. This seems to hold coherence with the high number of individuals found of the hygrophyllic *Porcellionides pruinosus* (woodlouse) during the first few monitoring events (Table 1) which were greatly reduced after 2020, when environmental control became better managed in the herbarium. It appears that the relative air humidity levels of 30-40% currently maintained in the CDS herbarium are adequate to prevent an infestation.

Temperature, on the other hand, was found to be significantly associated with invertebrates overall, suggesting that there may be an important effect of temperature that should not be overlooked. Invertebrates are a large problem for natural history collections in the tropics, usually due to consistently higher levels of relative humidity, which encourages their development. The higher temperatures in these regions also play a role in providing the right habitat for their growth (Hall, 1988; Pinniger and Harmon, 1999). Maximum temperature met and/or exceeded 25°C during six of the nine monitoring events between 2017-2021 at CDS, even though the number of days this threshold was exceeded was not significantly associated with invertebrate numbers. Species of *Liposcelis* (an invertebrate found in CDS) are parthenogenetic, and at temperatures over 25°C populations grow rapidly, increasing the risk of infestation (Pinniger and Harmon, 1999). Temperature in the CDS was found to have a greater association with outdoor data than humidity, which may explain why this variable is also associated with more invertebrates in the herbarium. This suggests that in the CDS, there is a need to maintain a tighter control of temperature given these results, whereas humidity levels are appropriate at present levels (between 30-40% RH). The current environmental management protocol in the collections consists of daily emptying of dehumidifiers in order to consistently maintain low humidity, whereas temperature is set at 22°C on each air conditioning unit and that level is rarely modified. In the CDS, the ancillary collections play a crucial role in current research projects, and seed collections are known to be of particular risk of infestations due to the high nutritious content of seed heads (Pinniger and Harmon, 1999). As RH is mentioned as being a big factor in the presence of pests, it is tightly controlled at the CDS. As mentioned earlier, serious herbarium pests such as *Lasioderma serricorne* (cigarette beetles) can occur in conditions of high temperature.

The fact that there was no association between the number of days above the temperature or RH limits and invertebrate abundance, however, suggests our current IPM has been effective. This likely means that the limits did not reach dangerous levels for too long before they were brought back down below 24°C and 50% RH. While temperature and humidity control aid this, other protective IPM measures such as specimen quarantining, insulated containers and fumigation also play a role. The results from the third objective showing that there is a correlation of environmental conditions with the outdoor conditions mean the environmental control in the CDS is not perfect, however, the results from testing the number of days exceeding these thresholds shows that despite this, the current conditions as a whole are effective at preventing the entry and population growth of pests. For instance, following the implementation of our current IPM, only 7 individuals of L. serricorne have been found in pest traps since, with none captured since 2019 (Supplementary Table 1). This shows that our IPM measures, coupled with strict environmental controls, can effectively halt the development of invertebrates and their population growth.

Future projections for climate change may have an impact on the way natural history collections are maintained. Puerto Ayora, where the CDS herbarium is based, has a yearly range of RH of approximately 85-90%, and a mean temperature of 30-30°C, although this area (the dry zone) is expected to become warmer and wetter (Trueman and D'Ozouville, 2010). Another study in the Galapagos showed predictions of increased seasonality (that is, an increase in mean warm season temperatures and a decrease in cool season temperatures), as well as increased annual rainfall in the islands over the coming decades (Wolff, 2010). This is another point to consider in terms of the effects of outdoor on indoor environments, as weather impacts may be stronger in future and possibly call for a need of more protective herbarium infrastructure and/or tighter ambient control within our IPM to prevent infestations. We recognise that the buildings natural history collections are housed in are never perfectly insulated, especially in the tropics, regions where weather can be more unpredictable, or institutions with less funding, as this is difficult and expensive. This shows coherence with recommending stricter monitoring and more conservative temperature and RH thresholds for indoor conditions, to provide a buffer for the impact of these variables. Ensuring preventative pest management through environmental control and physical insulation can also help prevent the need of using strong chemicals and pesticides. This is important to consider not only due to human impact but also its effect on local biodiversity, especially due to the herbarium's location within the Galapagos National Park.

Between January and March, the rainy season in the Galapagos islands often leads to leaks in some old buildings in the research station due to changes in humidity which can affect wood. There was one instance of a reported leak into the herbarium in February 2020 which was sealed immediately after being discovered. This could have caused an increase in humidity during this period, but the numbers suggest that the dehumidifying units were sufficient to curb this effect. It is important to address, however, that the thermohygrometers used throughout this study were not previously assessed or calibrated, so their absolute accuracy is a limiting factor in this study. That said, the measurements collected with these thermohygrometers still allow us to evaluate the relative association between temperature, RH and invertebrates in this study. There are herbarium cabinets that contain their own temperature and RH readers which would provide more precise measurements of environmental conditions of stored specimens, for instance, *ampfab* herbarium cabinets (https://ampfab.co.uk/herbarium-cabinets/).

Certain issues which should be mentioned regarding trapping and identification methodology were that many invertebrates, 12 of 55 species, were only identified to family or order level, and 1 was unidentifiable. The entomological team from the Terrestrial Invertebrate Collection of the Charles Darwin Research Station (ICCDRS) mentioned that sticky traps make genus or species -level identification difficult as individuals are often damaged when moved to examine body parts that are necessary for identification (*pers. comm*. Lenyn Betancourt, 2021). Correct identification of trapped invertebrates at every developmental stage is key in establishing the necessary protocols to prevent infestations. A potential solution to this issue could be to use different types of traps in future, such as UV-light traps and pheromone lures, which may attract other invertebrates depending on their size or biology that are also important to monitor in collections (Querner, 2015; Windsor *et al.,* 2015).

Conclusion

Our study of the CDS herbarium found that, in a plant collection in the tropics, 1) temperature had a significant effect on invertebrates found in the collection, 2) exceeding the thresholds for short periods of time (days) did not affect numbers, and 3) there is a correlation between outdoor and indoor environments, in particular temperature. Since buildings are not completely sealed, we suggest maintaining stricter control and monitoring of indoor environmental conditions, particularly temperature. Sealing and securing entry points to the collections will also help with buffering the effect of outdoor climate and protecting specimens. In any IPM plan, prevention is key to evading pests, which includes controlling for collection surroundings, building entry zones, collection archiving, environmental conditions, and even staff habits. Herbarium pests such as the cigarette beetle, *Clogmia* sp., springtails, silverfish, woodlice and cockroaches are attracted by hot and humid environments due to their feeding or breeding activity (Pinniger and Harmon, 1999; Querner, 2015; Notton, 2018). Monitoring temperature and relative humidity range, as well as ensuring other protective barriers are held in place in natural history collections can help reduce the use of chemicals to prevent infestations in tropical regions of high biodiversity. Through our study we found that suggested best-practices of maintaining temperature in the range of 21-23°C and a relative humidity of 40-55% are sufficient for tropical herbaria without having protective controls strong enough to completely eliminate the effect of the outdoor climate.

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Supplementary Table 1. Values of maximum relative humidity and temperature, total number of species and individuals per monitoring period.

Monitoring period	***Total species***	***Total individuals***	***Maximum relative humidity (%)***	***Maximum temperature (°C)***
May 2017 - Dec 2017	23	159	61	24
Dec 2017 - Jul 2018	23	127	57	25
Jul 2018 - Feb 2019	18	59	53	25
Feb 2019 - Sep 2019	12	60	64	29
Feb 2019 - Jan 2020	44	466	47	24
Jan 2020 - Apr 2020	19	24	42	25
Apr 2020 - Jul 2020	23	33	41	25
Jul 2020 - Oct 2020	14	14	50	23
Oct 2020 - Jan 2021	12	15	31	24
Jan 2021 - Apr 2021	43	99	46	25

Supplementary Table 2. Table of models implemented to test the 3 objectives of the study, which were to: 1) test for any association of maximum temperature and/or maximum relative humidity with the abundance of invertebrates and pests found inside the collections; 2) evaluate the effect of exceeding the current recommended environmental thresholds on the presence or abundance of insect pests; and 3) evaluate the effect of the local climate on the temperature and humidity within the herbarium to test the limitation of maintaining an herbarium in tropical climates.

Objective Number	***Objective***	***Model***	***Variables***
1	Testing effect of maximum temperature on invertebrate abundance	glmer with poisson, compared to reduced model without maxtemp using LRT	invertebrate abundance, maximum temperature (scaled), maximum humidity (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
1	Testing effect of maximum humidity on invertebrate abundance	glmer with poisson, compared to reduced model without maxhum using LRT	invertebrate abundance, maximum humidity (scaled), maximum temperature (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
1	Testing effect of maximum temperature on pest abundance	glmer with poisson, compared to reduced model without maxtemp using LRT	pest abundance, maximum temperature (scaled), maximum humidity (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
1	Testing effect of maximum humidity on pest abundance	glmer with poisson, compared to reduced model without maxhum using LRT	pest abundance, maximum humidity (scaled), maximum temperature (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
2	Testing effect of number of days above temperature threshold on invertebrate abundance	glmer with poisson, compared to reduced model without days above temp threshold using LRT	invertebrate abundance, days above temperature threshold (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
2	Testing effect of number of days above humidity threshold on invertebrate abundance	glmer with poisson, compared to reduced model without days above hum threshold using LRT	invertebrate abundance, days above humidity threshold (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
2	Testing effect of number of days above temperature threshold on pest abundance	glmer with poisson, compared to reduced model without days above temp threshold using LRT	pest abundance, days above temperature threshold (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
2	Testing effect of number of days above humidity threshold on pest abundance	glmer with poisson, compared to reduced model without days above hum threshold using LRT	pest abundance, days above humidity threshold (scaled), days in monitoring period (scaled); random variables of order, unique trap ID
3	Testing correlation of outdoor humidity with herbarium RH	correlation test using Pearson method	mean outside air humidity and mean herbarium relative humidity
3	Testing correlation of outdoor with indoor herbarium temperature	correlation test using Pearson method	mean outside temperature and mean herbarium average

The history of the dried *Mola mola* (Linnaeus, 1758) and *Mola tecta* (Nyegaard, *et al.*, 2017) specimens in the collection of Naturalis Biodiversity Center, Leiden.

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Abstract

This study provides an overview of the historical preparation techniques used on the *Mola mola* and *Mola tecta* specimens in the collection of the Naturalis Biodiversity Center, Leiden. The current state of the specimens is examined to ascertain these techniques, and observations are set against the contextual framework of a selection of 19th century taxidermy handbooks. The specimens came into the collection in three periods (1826-1836, 1889-1896 and 1940) and the techniques used to prepare them are compared to establish a standard for each period. Archival material and publications on these specimen have been used to gather background information on how these specimens were collected, in order to place them in their historical context. It can be concluded that the preparation techniques are very similar intra-period, and were certainly based on instructions from the museum and the experience of one (team of) preparator(s). The changing techniques from the early to the late 19th century can be attributed to changes in taxidermy practices as well as the fact that these specimens were larger since they were collected locally. This has opened up further possibilities for study, including a more thorough physical examination using modern technology and comparative studies between the techniques described here and other specimens in the Naturalis collection to gather more information about 19th century preparations in general.

Keywords: *Mola mola, Mola tecta,* Object Biography, Naturalis Biodiversity Center, Material History, Taxidermy, Preparation Techniques, 19th century, Museum Collection, Collection History.

Introduction

There are many specimens sitting in the collections museums around the world with almost no information attached to them. That is not to say there is no information on these specimens, but most of the time the information is not linked to the specimens, and there has been little time and/ or money to place them in their proper context. Only on special occasions do most old specimens get researched. The restoration of a large dried *Mola mola* (Linnaeus, 1758) and *Mola tecta* (Nyegaard, Sawai, Gemmell, Gillum, Loneragan, Yamanoue & Steward, 2017) specimens at Naturalis Biodiversity Center, Leiden presented the opportunity to undertake additional research into their history, and how they were prepared over time.

This paper is the result of the following study, which aimed to give a historical context to these specimens as well as a detailed overview of the techniques that were used to prepare them.

The main goal of bringing all this information together was to be able to preserve these specimens more effectively, and to learn more about the history of the acquisition and preparation of specimens at Naturalis more broadly.

Naturalis currently has nine dried *M. mola* specimens and one dried *M. tecta* specimen in their collections. This study leaves out the two most recently acquired *M. mola* specimens, one of which was prepared in recent memory and one of which was prepared after this study was finished. Of all the specimens only the *M. tecta* is currently on display, in the Live Science hall of the museum. This study encompassed specimens RMNH.PISC.D.2676, RMNH.PISC.D.2677, RMNH.PISC.D.2678, RMNH.PISC.D.2679, RMNH.PISC.D.2059, RMNH.PISC.D.2757, RMNH.PISC.D.2758 and RMNH.PISC.D.2865 (Figure 1), identified within the figures and after their first mention by their final four digits.

Methods

This project into the history of the *Mola* collection had two sides, the collection history and the material history. For the collection history written sources were used, from archival material such as indexes and correspondence, to published accounts of the specimens and the labels attached to the them. The material history was established through a physical non-invasive study of the specimens as well as a literature study

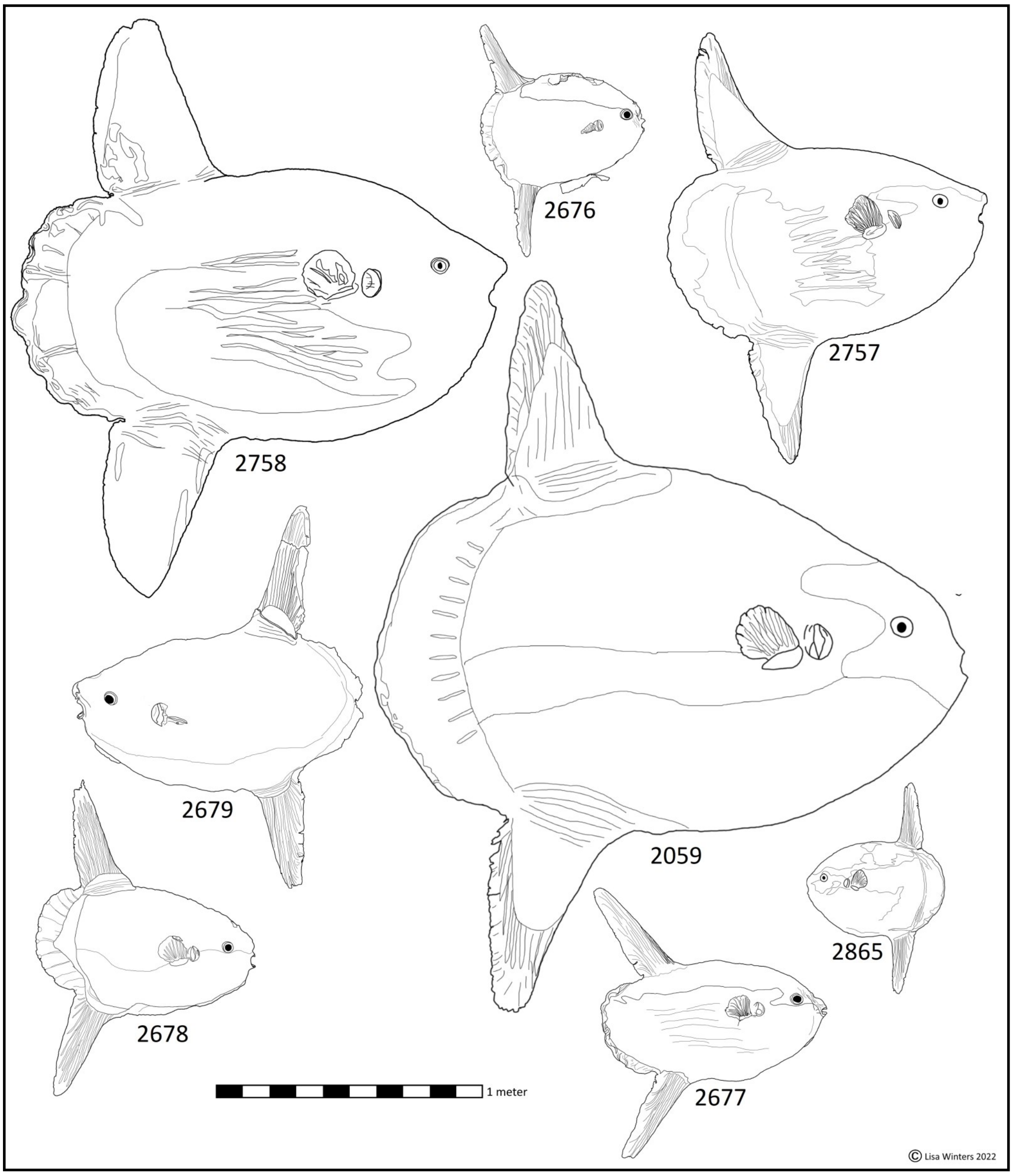

Figure 1. An overview of the dried Mola specimens in the Naturalis collections used in this study. Technical drawings by Lisa Winters, 2022.

of 19th century fish preparation techniques. All these sources were combined to reconstruct the most likely history of these specimens from the moment the fish died to the final preparation before being added to the shelves of Naturalis.

Naturalis Biodiversity Center, Leiden

Naturalis was founded as the 'Rijksmuseum voor Natuurlijke Historie' (National Museum for Natural History, shortened to RMNH), in 1820 by Coenraad Jacob Temminck (1778-1858). As chronicled in Gassó Miracle's scientific biography (2021), Temminck was a zoologist with a large collection of bird specimens on which he published many articles. He was also in good standing with Louis Napoléon Bonaparte (1778-1846), then the monarch of the Kingdom of Holland, for which he catalogued museum objects. In 1813 King William I (1772-1843) came to power, and Temminck made sure to establish good connections with the new government. He convinced William I to found the RMNH from the collections of the University of Leiden and the royal natural history cabinet as well as his own collections. In order to gain status for his new country of The Netherlands, William I sponsored Temminck in establishing even greater collections for the new national museum. In this context Temminck corresponded with many physicians and scholars in the Dutch colonies in order to collect specimens, as well as employing natural historians especially for this purpose. See also Borren and Drieënhuizen (2022) for a discussion on decolonizing natural history collections in the Netherlands.

The acquisition of the dried *Mola* specimens

For this study, seven dried *M. mola* and one dried *M. tecta* specimens from the collections at Naturalis were compared (Table 1). They can be divided into three groups based on their age; four specimens from approximately 1826-1836, three specimens from around 1890 and the most recent one from 1940. The oldest three specimens were collected abroad, all by men employed to collect as many different biological specimens as they could for the museum. It is not certain in what the order the first three sunfishes arrived at the museum. None of them have a date recorded on their labels, and while there are acquisition lists that record the work done by collectors these often simply list the animals in bulk. The dates can however be narrowed down to a range of a couple of years due to the combination of collector and country of origin. As the collectors were employed by the museum, their travels were well recorded as justification for their expenses (RMNH Jaarverslagen/Annual reports 1826-1835). One way to order them, which I will use in this article, is by specimen number. It is possible that the assigned numbers are also an indication for the order in which the specimens arrived at the museum, however these numbers have been reassigned over the years and cannot be taken as fact.

The first specimen, RMNH.PISC.D.2676, is from the Cape of Good Hope in South-Africa and was collected by Hubertus Benedictus van Horstok (1794-1838) between 1826 and 1834. He worked in Cape Town as a physician and surgeon and did his zoological and collection work on the side (S2A3 Biographical Database of Southern African Science, 2022). Horstok specifically collected ichthyological specimens for the RMNH, including our young *M. mola* of about one and a half years old (ages all based on Nakatsubo and Hirose, 2007).

The second specimen, RMNH.PISC.D.2677, was collected at Livorno, Italy, by François-Joseph Cantraine (1801-1868) between 1827 and 1833. Cantraine was a zoologist with a focus on molluscs and fish and studied preparation techniques at Leiden University (BESTOR, 2022). The RMNH sent him to Italy to observe birds, during which time he also collected a two-year-old *M. mola* specimen.

The third specimen, RMNH.PISC.D.2678, was collected in Japan by Heinrich Bürger (1804/6-1858) sometime between 1830 and 1835. During this time only people under the Dutch government were allowed to enter Japan for trade and study, and Bürger gained this access by working as an apothecary and assistant to Philipp Franz von Siebold (1796-1866) in employ of the RMNH. Siebold was a physician and studied Japanese flora and fauna, while Bürger collected copious amounts of specimens for the museum (Boeseman, 1947; Steenis-Kruseman, 1962). For a discussion of the relationship between the Netherlands and Japan at this time, and the importance of Siebold and scientific collecting abroad, see also Plutschow (2007). The *M. mola* specimen he collected and prepared for the RMNH was also approximately two years old.

The fourth specimen, RMNH.PISC.D.2679, arrived at Naturalis in 1836 and is both the first "Dutch" *M. mol*a in the collection and the first reliably recorded sunfish caught along the Dutch shore (Deinse and Verhey, 1964, p.66). It is also the biggest up till then, at approximately three years old. While the label simply reads "Hollande", it may possibly be from Katwijk aan Zee (Deinse and Verhey, 1964), however the exact location is undetermined.

The specimens from around the 1890's were all either caught or washed up along the Dutch shore and sent almost fresh to Naturalis. Due to the proximity to the museum, specimens of a much larger size could now be collected. *Notes from the Leyden Museum* (Lidth de Jeude 1890 and 1892; Reuvers 1897), presents examinations of all three specimens in the state they arrived at the museum, including extensive measurements as well as some notes on who donated them.

In December of 1889 an adult *M. tecta* was found stranded along the coast of the island of Ameland. The mayor of the island, D.W.J. baron van Heeckeren (1857-1904), sent the dead fish to the RMNH to be studied. This specimen, RMNH.PISC.D.2059, is an adult *M. tecta* of almost ten years old and is the largest specimen in the collection at 2.80 meters tall.

In December of 1891 another sunfish washed ashore at Callantsoog, close to the Zoological Station at Den Helder. It was brought to the attention of the Zoological Station and the director, P.P.C. Hoek (1851-1914), sent the specimen on to the RMNH. It is now labelled as RMNH.PISC.D.2757 and it's the smallest specimen of this period standing at 1.59 meters tall and being approximately four years old.

Another large specimen was caught by fishermen in the Den Helder area in November 1896, and Hoek also sent this specimen to the museum. It was still alive when it first arrived at the Zoological Station, so when it arrived at the RMNH it was fresh and in very good condition. After a photograph was taken and it was examined for a description (*Notes from the Leyden Museum,* Reuvers 1897) the specimen was prepared and is now part of the collection as RMNH.PISC.D.2758. The description states that the specimen was 2.18 meters tall, which would suggest it was around eight years old when it was caught.

The final specimen, RMNH.PISC.D.2865, is from 1940, which presents quite a gap in the dried *Mola* collection. This is the 33rd of the recorded sunfishes caught or washed ashore in the Netherlands, though it is only the fifth that was prepared as a dried specimen. While at least five of the other sunfishes that stranded between 1935 and 1941 were sent to Naturalis, they were dissected and either disposed of or (partially) preserved in alcohol (Van Roon and ter Pelkwijk, 1939; Van Roon, 1942). Other than the information on its label, that it was found at the Wieringen dike on the fourth of July in 1940 and sent to the museum through the interference of the Zoological Station, nothing else is known about the history of this specimen. It is the youngest and smallest specimen in the collection, standing 0.74 meters tall and estimated as being only one year old at the time of preparation.

Whether coming from overseas or sent immediately from the Dutch coast to the museum itself, all these specimens needed to be prepared for dry conservation. The ones from overseas must have at least been fully gutted and have had the skin treated with chemicals to keep from spoiling on the journey. The specimens that came to the museum "fresh" would have immediately been prepared and mounted as well. The museum had a team of preparators working full time on incoming specimens (Holthuis, 1995).

Preparation methods in the 19th Century

In 1825 C.J. Temminck, founder and director of the RMNH from 1820 to 1858, wrote a manual on the preparation and conservation of animal skins. The method he describes here for the preparation of large fish is not only a basis for the way the *Mola* specimens were prepared, but set the standard for fish preparation for decades (Gassó Miracle, 2021). He stated that the usual way of preparation, in which an incision was made along the ventral aspect, compromised part of the specimen for study. Instead, an incision should be made horizontally along one side of the specimen from head to tail. One side would be damaged, but the other side would still be intact for study and exhibition. The innards had to be removed through this incision and the skin cleaned and rubbed with a preservative. He describes laying the "fresh fish" on a plank of wood and pinning down the fins and tail on paper or cork (Temminck, 1825, p. 16). The specimen is then dried in 24 hours (in a European climate) after which it is easier to remove the skin from the muscles through scraping. Cartilage had to be cut away with sharp scissors, which means that some bones and cartilage were often left in the fins and head. The remaining skin has to be rubbed with arsenic soap mixed with plaster to keep the skin firm. The prepared skin was stuffed with wood wool, straw, bast fibres or similar materials. The preparator did not have to sew up the incision. Notes had to be taken on the colours of the living fish to paint the specimen after the preservation process. Temminck wrote these instructions specifically for use at the RMNH, as is stated clearly in his title "Instruction, how to handle objects of natural history with the goal of properly shipping and conserving them; for use of the National Museum of Natural History in Leiden" (my translation; Temminck, 1825).

In 1833 Thomas Brown (1785-1862) wrote a book on taxidermy in which he specifically addressed the stuffing and mounting of large fish. In accordance with the Temminck method he describes an incision along one side of the fish as well as the scraping of skin and the cutting away of cartilage. For the mounting of the skin he describes that tissue paper needs to be applied to the skin in order to retain the colours and the whole skin is to be rolled into a wet cloth. Large fish need a stick for a centre support, in addition to tow and cotton, and have to be sewn up. The prepared fish is set to dry in the open air without exposing it to direct sunlight. The orbits are then filled with cement and cotton, and glass eyes are added. The cartilage around the eyes is mimicked with a mixture of gum arabic and powdered starch. Finally, the skin is varnished and dried again.

As the century progressed, other methods of fish preparation became more popular, especially the modelling of skin around a frame. In 1885 it became common to whittle a solid wooden frame for smaller fish, around which the fish skins were wrapped while they were still wet. The skins then dried against this frame (Reed and Reed, 2012, Chapter 6: Mounting Fish). Due to this wooden frame the skin could easily be mounted by nailing a plank to the "ugly" side where the incision was made. The mounted fish was then hung on the wall. Manuals don't explain how this method of modelling the skin around a frame and mounting it can be used on large fish.

Until the late 20th century these existing preparation methods did not change much, except for the chemicals used in preservation (See also Dickinson, 2006). The techniques mentioned in the literature are very noticeable in the specimens, especially when you see them grouped into the periods they were created in. Apart from the techniques mentioned in the literature, each period also has its own particular style of preparation. These techniques are described here, grouped by time period, in order to find out their origins.

Specimens from 1826 to 1836

Of the four specimens that entered the collection between 1826 and 1836, three came from collectors abroad. This means that all the skins were prepared by different people with access to different materials and in different environments. The Fauna Japonica by Siebold *et. al.* (1850, p. 288) suggests that at least one specimen (2678, Japan) was stuffed before it arrived at the museum, but it is not certain in what state the other specimens arrived. The only exception is the Dutch specimen (2679) which arrived fresh to the museum, and was prepared by museum staff. Despite their different provenances the preparation methods are very similar (Figure 2). See also Tables 1 and 2 for an overview of all specimens.

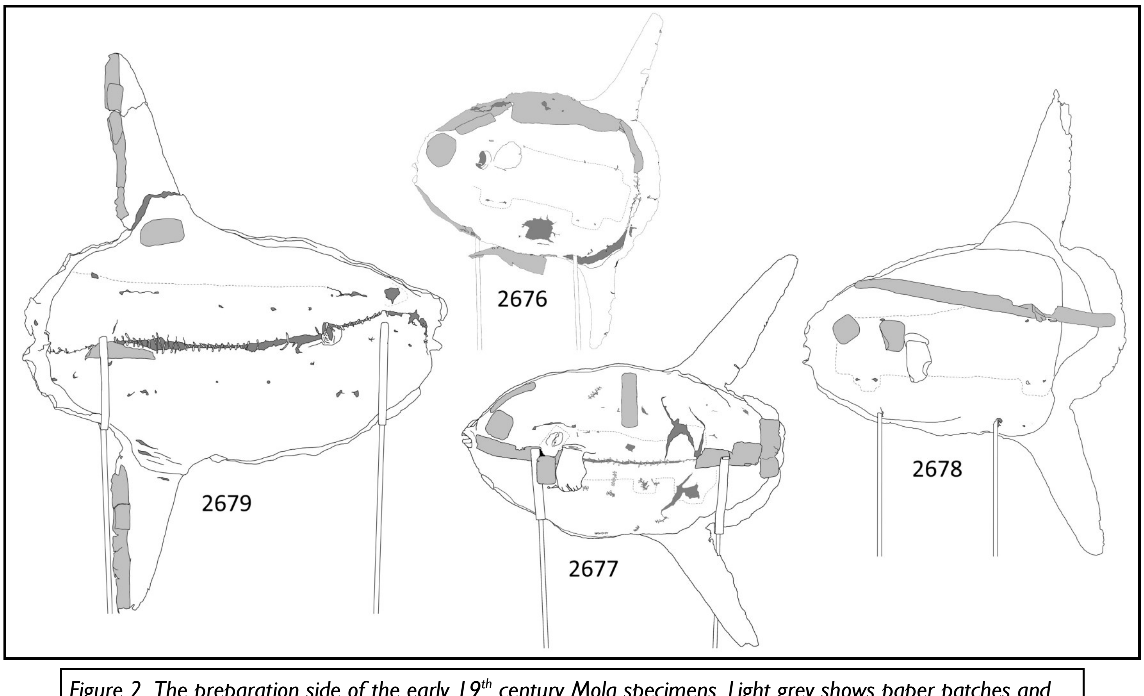

Figure 2. The preparation side of the early 19th century Mola specimens. Light grey shows paper patches and dark grey shows damage where the stuffing is visible. Technical drawing by Lisa Winters, 2022.

Table 1. Overview of the acquisition circumstances of the Mola specimens.

	Date (d-m-y)	Location	Collector / donated by	Size (lxh, cm)	Age (y)	State of arrival
RMNH.PISC.D.2676	1826-1834	Cape of Good Hope, South-Africa	H. B. van Horstok (1794-1838)	65x86	1,5	Preserved skin
RMNH.PISC.D.2677	1827-1835	Livorno, Italy	F. J. Cantraine (1801-1868)	85x102	2	Preserved skin
RMNH.PISC.D.2678	1830-1835	Unknown, Japan	H. Bürger (1804/6-1858)	83x120	2	Stuffed skin
RMNH.PISC.D.2679	1836	Katwijk aan Zee, the Netherlands	Unknown	110x144	3	Fresh
RMNH.PISC.D.2059	13-12-1889	Ameland, the Netherlands	D.W.J. baron van Heeckeren	223x280	10	Fresh
RMNH.PISC.D.2757	05-12-1891	Callantsoog, the Netherlands	P.P.C. Hoek	122x159	4	Fresh
RMNH.PISC.D.2758	19-11-1896	Den Helder, the Netherlands	P.P.C. Hoek	179x211	8	Fresh
RMNH.PISC.D.2865	04-07-1940	Wieringen dyke, the Netherlands	Unknown	52x74	1	Fresh

Table 2: Overview of the preparation techniques used on the Mola specimens.

	Incision side	Incision placement	Materials for stuffing	Holes for pinning
RMNH.PISC.D.2676	Left	Along the ventral, top of the head	Hay, bast fibres	No
RMNH.PISC.D.2677	Left	Beak to clavus	Hay, bast fibres	In the dorsal and anal fin
RMNH.PISC.D.2678	Left	Forehead to clavus	Hay, bast fibres	In all fins and along the edge
RMNH.PISC.D.2679	Right	Beak to clavus	Hay, bast fibres, plaster	No, pectoral fins missing
RMNH.PISC.D.2059	Left	Round and into fins and clavus, fin to fin	Unknown	Unknown
RMNH.PISC.D.2757	Both (R+L)	Round and into fins and clavus (R), fin to fin (L)	Wooden frame	In the pectoral fin
RMNH.PISC.D.2758	Right	Round and into fins and clavus	Steel frame, plaster	Unknown
RMNH.PISC.D.2865	Right	Round and into clavus	Metal rods, plaster	In the pectoral fin

The following description of the preparation methods is applicable to all specimens. An incision was made to remove all the flesh and most of the bone and cartilage. Part of the skull (the beak is visible, see Figure 5) and the bones in the fins are still in place. The skins have been stuffed with hay in the middle and tow in the more delicate parts and the main incision has been stitched closed with two twined threads. The stitch used looks like a single shoelace pattern, as seen on Figure 3. One side of the fish has been prepared to look "alive", including the pectoral fin positioned away from the body, a coloured varnish and an artificial eye. This eye consists of a gum arabic disk with uneven edges, painted to look like an eye. The eye is placed on top of the hole left in the skin and attached through an unknown method. The iris of the eye is a golden-brown, with a large pupil (Figure 5). This type of artificial eye is common in dried fish specimens in the Naturalis collection, from a broad range of species and sizes. The mouth has also been worked to look realistic, with the inside of the bone beak modelled smooth with gum arabic and painted red. Original damage to the skin has been patched up with paper strips, including a long strip covering the line of the incision and a diamond-shaped patch to cover the hole for the eye that has not been prepared. The original mounting method is not known, though the "bad" side of the fish shows a horizontal rectangular discolouration. The skin is lighter here, which suggests that something has protected it from dust, dirt, or other pollution. The specimens also all show holes within this discoloured section, at least four on the top and four on the bottom, spaced two-by-two (Figure 3).

There are also a couple of materials and methods present in some specimens that are not present in others. The only thing that is different in each

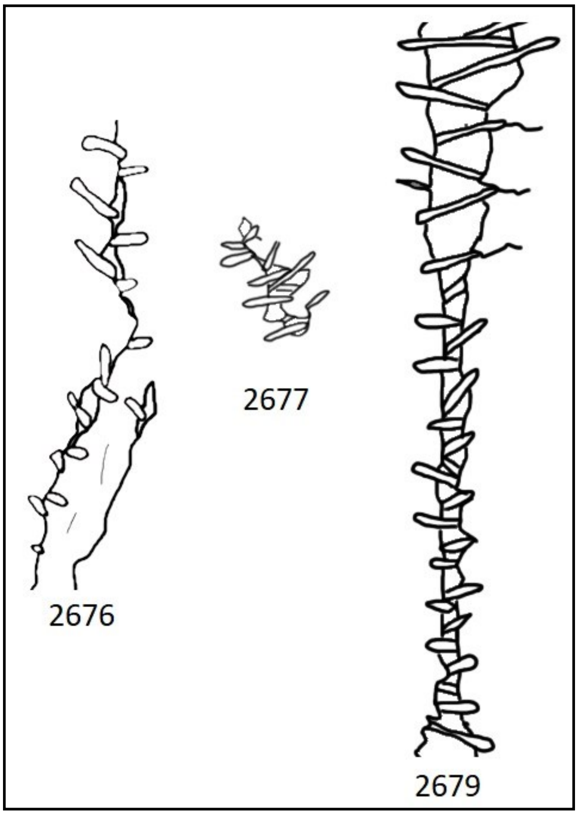

Figure 3: Examples of stitching on three Mola specimens. Technical drawing by Lisa Winters, 2022.

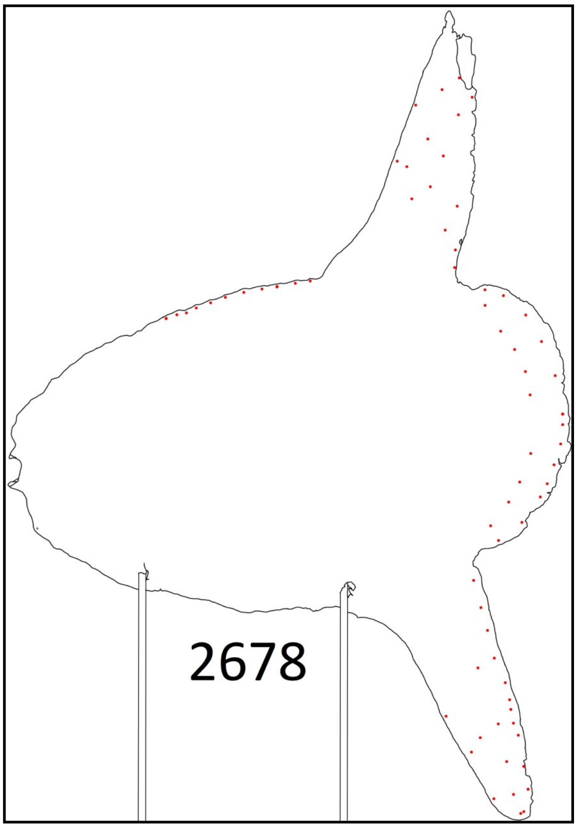

Figure 4: All holes visible in specimen RMNH.PISC.D.2678 from Japan. Technical drawing by Lisa Winters, 2022.

specimen is the placement of the incision. The specimen from the Cape of Good Hope (2676) has been cut along the ventral line from mouth to anal fin, contrary to Temminck's instructions. This is interesting as Horstok routinely collected fish specimens for the museum, and applied the recommended method for the incision in some of his other large fish specimens like an *Odontaspis taurus* (RMNH.PISC.D.2516) from the same place and period. His *Mola* specimen also has a large hole on top of the head, though whether this was damage to the skin or part of the original incision is not clear. The other three specimens follow Temminck's handbook more closely with an incision from the head to the clavus along one side of the body (Figure 2, in some cases (partially) covered up with paper strips).

The Dutch specimen (2679) is the only specimen from this period with the incision on the left side. It has also been reinforced with plaster on the inside of the right side. Both characteristics can be attributed to it having been caught in the Netherlands, enabling bigger size and thus requiring reinforcements as well as being the first *Mola* to be fully prepared by Naturalis' staff.

Temminck's instructions also mention pinning the fins down to let them dry in the correct position. This is especially visible in the specimen from Japan (2678) which shows holes along the fins as well as along the ventral and dorsal sides (Figure 4), which are still pinched and unstuffed. This unstuffed edge is also present in two other specimens (2679 and 2677), though there are no signs of holes here. This edge could suggest the difficulties of stuffing the skin fully without breaking it or loosing its shape. The only other specimen that shows holes for Temminck's pinning method is the one from Livorno (2677) so it was not consistently used during this time.

With regards to a possible mounting structure, the Dutch specimen (2679) has three more sets of holes in the discoloured section. It also has rust and even pieces of nail left in some of the holes, which are present in the specimens from the Cape of Good Hope (2676) and Japan (2678) as well. The presence of holes and nails suggests even stronger that the discolouration is linked to a mounting mechanism, traditionally where the fishskin would be hung on a plank on the wall. There is however no outside sign of an inside structure, leaving the question of what the mount would be attached to unanswered. It is also possible the colouration is connected to the fish drying on one side, with the holes created as a result to keep the skin in place around the incision. However, this is not a practise described in any of the consulted literature.

The original mounting mechanism has been removed in all cases, and replaced by metal rods either sticking into the ventral side of the fish or supporting the specimen with Y-shaped prongs. All the specimens have a wooden base supporting the rods, though the base of the Dutch specimen (2679) has been treated to look like stone where the others are all painted a similar white.

The fact that all these specimens look so similar in their preparation techniques, with little details that are not specified in the prevalent handbooks (the gum-arabic eye and inside of the beak, the diamond shaped paper patch over the eye, the double thread and stitching pattern), suggests that a (team of) preparator(s) at the Naturalis museum patched up all the skins in a similar way before entering them into the collections. The skins from overseas might still have needed stuffing, and even a pre-stuffed skin (such as is suggested about the Japan specimen) would probably have needed some minor additions or alterations. This seems the most plausible option, since the collectors were not all trained at Naturalis and it is unlikely they would have such a specific shared way of preparing. If the overseas collectors did have such specific instructions, you would expect more similarities in things such as the incision pattern and holes for pinning.

Specimens from 1889, 1891, and 1896

These three specimens all arrived at Naturalis fresh, and were prepared by museum staff. There is a definite departure from the preparation techniques used in the first four specimens, which is likely a combination of the new popular method of stretching the skin over a frame and the much bigger size of these specimens. Both the Ameland (2059) and Den Helder (2758) specimens have been completely restored in recent years (2018 and 2021 respectively), which makes it difficult to ascertain the specifics of the original preparation techniques. The Ameland specimen (2059) especially has been difficult to study, as it is currently on display in an inaccessible place. The recent restorations also however gave more insight into the internal structure of the specimen, which helps to sketch out the broad lines of the preparation techniques.

The most obvious similarities between these specimens is that they have an internal frame around which the skin is fitted, as well as that both sides of the specimens have been prepared to look realistic. The internal structure allowed for the use of nails instead of or in addition to stitching. The specimen from Callantsoog (2757) comes closest to the examples in literature as it has a wooden frame, though this one is hollow and made of slats. The head has been modelled with plaster but on the main body the skin is immediately nailed to the wood. The specimen from Den Helder (2758) has a steel frame with plaster modelled around it. In all these specimens the plaster is not only used to provide a general frame but also to model details in the anatomy of the fishes. The heads for example have been modelled to show cheeks and other features, and particular attention has been given to the mouth which is painted pink and has a modelled tongue (Figure 5). During the restoration of the Den Helder specimen (2758) a piece of the beak was found under the plaster and removed, showing that even in the case of these larger and more recent preparations part of the bones were still kept in place, though covered. The Callantsoog (2757) has genitals modelled in plaster, and in the Den Helder specimen (2758) the skinfolds along the sides were found in the plaster in order to shape the dried skin.

Another similarity between these specimens and in contrast to the earlier specimens are the position of the incisions. A single incision was sufficient for the other preparations to remove the inside and stuff them back up with hay and tow, but in order to wrap the skin around a mount another type of incision was needed. These specimens have had a circle of skin removed on one side, with incisions going from this circle to the tops of the fins and clavus. The Callantoog specimen (2757) has an additional incision on the other side, going from the base of the dorsal fin to the ventral side of the anal fin (Figure 6 and Table 2).

The final difference between the first set of specimens and this one is the way the eyes are modelled. The socket has been shaped in plaster, into which a glass eye with a half-ball shape 'D' has been inserted. The back of this glass half-ball carries the image of the iris and pupil. The eye has been inserted into the plaster and the skin with the eye-holes has been pulled over these artificial eyes. The cartilage around the eye has been modelled with plaster as well. These methods are very similar to the techniques described by Brown in 1833, including the plaster, glass eyes and gum-arabic cartilage. Apart from the similar method, the eyes themselves do not look similar.

Figure 5. Comparison in preparation between RMNH.PISC.D.2677, Livorno, (left) and RMNH.PISC.D.2758, Den Helder. Photographs by Lisa Winters, 2022.

Specimen from 1940

The final specimen (2865), from 1940, is the smallest specimen in the collection with a size of 52x74cm. Due to its small size many preparation techniques would have been possible, but it seems that the preparator has taken the latest *Mola* preparations as examples. The specimen has a metal wire- and plaster frame around which the skin has been wrapped. The incision also mirrors this choice of preparation, with a round flap of skin cut off one side and incisions going into the clavus. The frame would allow for the use of nails to secure the skin, however in this case a simple stitch with one thread has been used, and the seam has been covered up with a tar-like substance. Both sides of the specimen have been prepared, with the pectoral fins standing away from the body. Both pectorals also have a little hole from where it was pinned or hooked to stay in shape.

The eyes are also similar to the ones from the late

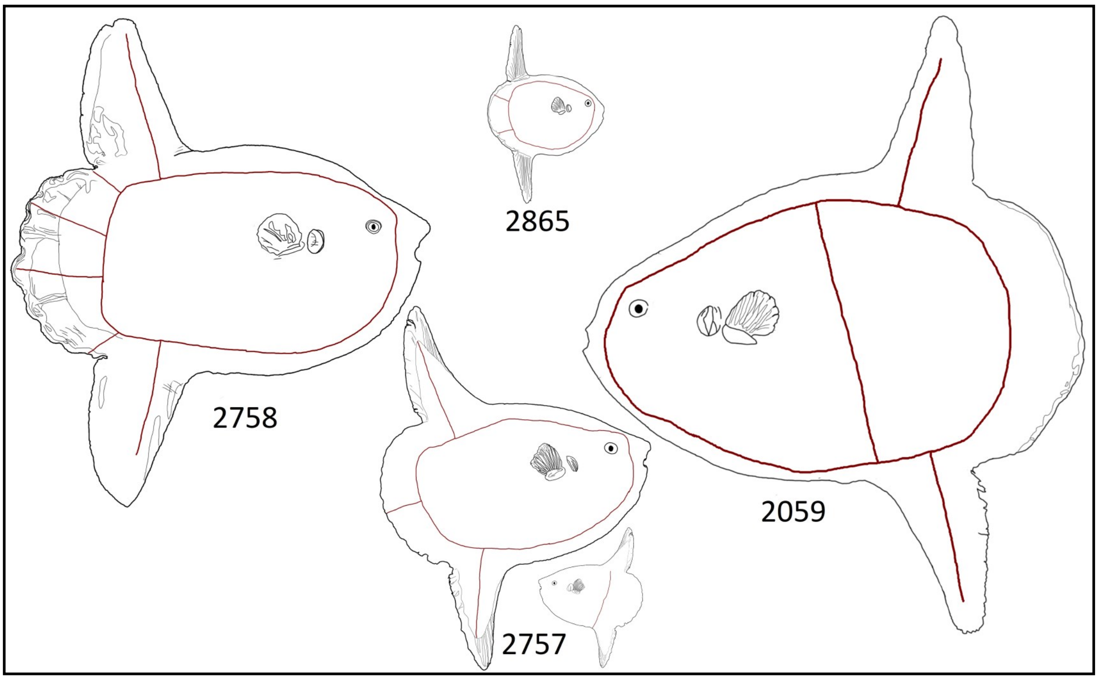

Figure 6: Incision patterns on the Mola specimens from the late 19th century and 1940. Technical drawing by Lisa Winters, 2022.

19th century, since it seems to be a plastic half-ball with a pupil painted or glued onto the back. Through the clear parts of the eye, the plaster into which it has been pressed is visible. Again, the eye seems to be inserted before the skin was pulled over the frame. The mouth has been modelled and does not show the original bone beak. It is pink in colour, again more in line with the late 19th century than with the red from the earlier ones. The skin seems to be heavily treated with conservation chemicals, but it has not been painted/varnished in the way all the other preparations have. Out of all the specimens, its skin looks the most like natural leather.

Due to the fact that there is only one specimen from this time period, it is difficult to say whether this technique was seen as a standard.

Conclusions and further research

This study has led to a description of the dry *M. mola* and *M. tecta* specimens in the collection of the Naturalis Biodiversity Center that can be used to properly conserve both the preparations themselves and the historical preparation techniques used on them in the past. From working with the restored specimens it is clear that a lot of the material history gets lost in this process in order to safeguard the specimen for future exhibition and conservation. A snapshot like this study could help in establishing a collection's historical value as well as their biological one.

The descriptions of the techniques used on these specimens can only hint at their value for the broader historical context of preparation techniques at the RMNH or in the 19th century more generally. We can conclude that their preparation was clearly following pre-existing guidelines. Even though fish skin preparations of this size were not very common, they were prepared in similar ways in their respective times. Many of the techniques used can be traced back to the literature on taxidermy at the time, especially the rules laid out for the RMNH staff and contractors by the founder and director himself, Temminck (1825).

While this first overview has documented many aspects of the preparation of these specimens, there are still a lot of questions left unanswered. Further research and more specialized techniques could help shine a light on some of these questions. For example, x-ray photography could be used to learn more about the internal structures of the specimens and their possible original mounting mechanisms. Another possibility is doing a chemical analysis of the skins, which could provide insights into the specific sources the preparators used for the preservation mixture they applied to the skins, as well as how the specimens can best be preserved today (for a related study, also see Allington-Jones and McKibbin, 2017).

This study can help understand 19th century taxidermy at Naturalis more broadly. If viewed from a technical standpoint, this can only really be done when comparing the techniques described here to other specimens in the collection. During my work in the collection depots I also came across two prepared shark skins that showed practices very similar to the earliest *M. mola* preparations, including the paper strips and sewing techniques. A comparative study of other fish- and animal preparations in the museum's collection from the periods around 1830 and 1890 could further shine a light on the RMNH's own preparation practices and the techniques that were specific to large fish.

From a sociological standpoint, this study suggests the importance that was attached to properly prepared specimens, not only for scientific use but also show to the public. This could be seen in the inference that RMNH preparators re-examined incoming specimen skins and patched them up, creating a "good" side to show off the fish's countenance in life. It could also be an answer to why a sunfish would have been chosen for a dry preparation in 1940, as it would have been easier to simply dissect it and/or preserve it in alcohol if it were only used for scientific study. This hypothesis is something that could again be explored through further study, especially in what would be the next step in a collection biography; how the collection was used.

During this study, the history of how these specimens were acquired was "re-attached" to these specimens. Even though the information was available in publications, in the archive and on the specimen labels, it was brought together here for the first time. Some of these specimens were collected from overseas by employees of the museum. Researching the circumstances in which specimens were collected could help us place specimens in a socio-historical context, and much more can be done on this front. This type of historical research does not only teach us how to care for our specimens, but could also be the first step in decolonizing our natural history collections.

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During my research at Naturalis I have received help and support from many of the museum staff, and I would like to thank everyone who has brainstormed with me about this project. My thanks goes out to three people in particular: Eulàlia Gassó Miracle, who was my first contact at Naturalis and gave me the opportunity to start doing collection research at the museum. Karien Lahaise, for helping me find my way in the Naturalis archives and combing through boxes with me. Finally, Esther Dondorp, for proposing the Mola collection to research, giving me access to the collection and supporting me in this project every step of the way. My gratitude goes out to you all, without you it would not have been possible!

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Mineral-specific issues in 3D scanning and printing for digital collections, outreach, and display

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Abstract

Three-dimensional (3D) scanning and 3D printing of natural history specimens presents interesting opportunities for informal and formal science education, as well as specimen preservation and display. Museum staff in several museums have begun scanning and making specimens available online. However, very few mineral specimens are available as scanned 3D objects, because minerals present unique challenges in scanning. Specifically, their variable surface reflection properties ("luster") and surface complexities make them complicated specimens to reproduce. This paper examines the variables involved in 3D scanning and 3D printing mineral specimens, lays out criteria for ideal candidates, and presents workarounds to common problems. In general, ideal mineral candidates for 3D scanning and 3D printing are opaque, with no overlapping components that create obscured cavities, have a distinctive form or habit, and have light colour and dull or earthy luster. Non-ideal candidates can still successfully scan and print, though workarounds are often required.

Keywords: 3D printing, 3D scanning, digitization, digital objects, mineral collections

Introduction

Over the last twenty years, science educators and researchers have started experimenting with 3D scanning and 3D printing of museum specimens for digital collections, outreach, and display. The Smithsonian X 3D Archive, launched in 2013, now holds more than 2,500 3D objects that can be downloaded and printed on at-home 3D printers (Smithsonian n.d.). The Digital Archive of Natural History has released dozens of 3D scans of insects (DiNArDa n.d.). The University of Michigan Museum of Paleontology has released collections of 3D fossils, including an entire *Allosaurus fragilis* skeleton (University of Michigan Museum of Paleontology n.d.). The GeoFabLab on Thingiverse provides dozens of fossils, geologic terrains, and a few crystal forms (GeoFabLab n.d.). At this point, an interested person could 3D print themselves almost an entire natural history museum (though, interestingly, there are very few mineral specimen 3D scans online).

These 3D digital objects have interesting applications in geoscience pedagogy, both formal and informal, especially in the wake of the 2020 COVID lockdowns that kept large numbers of students away from lab specimens and field trips. SketchFab collections like those of Sara Carena offer free digital collections of geologic terrains, rocks, and fossils. Horowitz and Schultz (2014) use 3D topographic maps in the classroom, Cases and Estop (2015) integrate 3D printed crystal forms into a crystallography class, and Savoian and Holt

(2017)use it to 3D print large-scale pollen models to teach about morphologies. Rocks and geologic specimens can also be 3D printed for classroom instruction (as explored in Squelch 2017, Ishutov *et al.,* 2018, and Hasiuk 2014). Hands-on materials are particularly helpful for students with vision differences (e.g., Travis 1990, Asher 2001, Permenter and Runyon 2003, Ceylan 2011). Additionally, 3D replicas can be used by exhibition designers to design mounts for display, reducing the risk of breaking fragile specimens.

However, in all these applications, 3D scanning and 3D printing of *mineral* specimens has not been explored, and very few digital 3D models of mineral specimens are available online. This is likely because mineral specimens present unique challenges for 3D scanning and 3D printing: their range of surface reflective properties ("luster"), changes in opacities, and surface complexities can make them challenging candidates for 3D scanning.

This paper examines the variables that affect 3D scanning and 3D printing of minerals, with the goal of presenting workarounds to common issues and laying out guidelines for ideal mineral candidates for 3D scanning and 3D printing. This paper is aimed at small-scale 3D scanning and 3D printing projects, appropriate for a university or museum mineral collection.

Methods

Technology

Three dimensional (3D) scanners have a wide range of capacities; Cieslik and Harris (2020) give an excellent overview of 3D scanning technology options for natural history collection digitization projects.

The project outlined in this article used a scanner with a budget and technical capacities manageable by a university: a Shining3D EinScan-SP, part of the Bryn Mawr College Makerspace. This is a structured light scanner: it projects a series of light-and-dark stripes onto the specimen (unlike a laser scanner, which projects a laser beam). Two cameras on either side of the projector then use triangulation to calculate the distance between themselves and each point the light touches. The scanner's software uses those triangulations to build a topographic map of the specimen. As the stage upon which the specimen sits is rotated, the object is scanned again, and a 3D topographic map of the object is built.

A desktop 3D scanner is appropriate for most specimens in a typical university collection. Unlike a laser 3D scanner, structured light scanners can also map surface texture, which allows the 3D objects to carry their original colours and patterns. The size requirements are appropriate for all but our largest and smallest minerals: 30 × 30 × 30 mm to 1200 ×1200×1200 mm. Most of the specimens in the Bryn Mawr Mineral Collection are between 40x40x40 mm and 1000x1000x1000 mm: the size you would hold in your hand (a "hand sample"). This is a common size range for mineral collections, because "hand sample" is a common geologic sampling size.

Before use, the scanner was calibrated using a dot calibration panel, and white balanced using white paper. For projects that require high fidelity colour, white balancing should be done using a photographic colour balance chart and a scanner built specifically for high-fidelity color scanning (ideally, higher 2D resolution than the 1.3Mpx Einscan used here). Minerals were scanned, then repositioned so any surfaces hidden in previous scans could be seen, and scanned again. This was repeated until each surface was scanned. Afterwards, watertight digital mesh models were constructed using the EXScan software. These watertight models interpolate to fill in gaps in the digital 3D structure so it can be printed on a 3D printer.

Watertight digital 3D models were then transferred to Ultimaker Cura software, where they were converted to 3D printable files. These were uploaded to an Ultimaker S5 Pro 3D printer in the Bryn Mawr Makerspace, and printed using Ultimaker PLA (polylactic acid) extruded material with water-soluble Ultimaker PVA (polyvinyl alcohol) as support material. PLA was chosen because it is commonly used in small-scale 3D printers, and one of the goals of this project was to produce 3D objects that could be printed at home by amateurs. However, in selecting materials for 3D prints, care should be taken to choose materials appropriate to the purpose of the project. For example, because PLA is a bioplastic derived from corn starch and sugar cane, it degrades when exposed to prolonged humidity. This makes it a more environmentally-friendly choice than other thermoplastics, but a poor choice for long-term use in a museum context. Care should also be taken in storing these materials; Stefaniak *et al.* (2018) demonstrated that 3D printed materials using PLA and ABS can off-gas styrene, a known carcinogen. In particular, acidic off-gassing could impact pyrite oxidation (see Larkin 2011 for a deeper discussion on pyrite preservation). Cimino *et al.* (2018) also review safety considerations in 3D printed materials in contact with art work.

For most specimens, the thickness of the 3D printed walls was set to 1 mm; specimens with fragile protruding components were set to 3 mm. After 3D printing, the 3D prints were soaked in water baths to dissolve the support material. It should be noted that any 3D printed material stored with specimens must pass accelerated aging tests (e.g., Oddy tests, Oddy 1973), to ensure that it does not emit gasses that could damage specimens.

Sample selection

The Bryn Mawr Mineral Collection is ideal for exploring the variables in mineral 3D scanning and 3D printing because of its breadth of specimens: the collection holds more than 40,000 minerals. This means there are dozens of specimens that fit the criteria of (for example) submetallic luster, dark colour, high surface complexity, interesting crystal form, etc.

All specimens reported here are from the Bryn Mawr Mineral Collection. Most are from the George Vaux Jr. Collection, assembled by Philadelphia naturalist George Vaux Jr. (1863 - 1927) from the mid-1800s to early-1900s, and donated to Bryn Mawr by his heirs in 1958. Specimens from this collection are labeled in the format V0000, where V indicates Vaux. This work also uses minerals from the Theodore Rand Collection, assembled by Philadelphia mineralogist Theodore Rand (1836 - 1903) in the mid- to late-1800s, and donated to Bryn Mawr by his heir in 1903; these are designated Rand, then a number. Finally, a few specimens from the Arndt Acquisitions are included, with the label AA and the number.

Specimens were selected with the goal of assessing the range of capabilities for the 3D scanning and 3D printing process. The variables considered were: colour, luster, habit, and surface complexity. Structured light 3D scanning is incompatible with anything other than opaque objects; however, some translucent or transparent minerals were included to test whether applying opaque materials to their outer surfaces could make them scannable. Size was not considered; all specimens were typical “hand sample” sizes.

Within the category of luster, minerals were selected to represent the most common surface lusters. “Adamantine” lusters refer to minerals that sparkle as a diamond would. “Waxy” minerals look like their surfaces are covered in wax (the microcrystalline quartz chalcedony often has this distinctive look). “Greasy” minerals look like they have a thin film of grease over the surface (large halite crystals often have this). “Vitreous” minerals look like they are made of glass, though this can be coloured or opaque glass. “Resinous” minerals look like amber or resin (sphalerite is the famous example of this). “Metallic” lusters look like polished metal (many pyrites), and “submetallic” look like unpolished metal (some hematite). “Pearly” lusters are nearly iridescent, like the inside of an oyster or a pearl (some talc). “Silky” lusters are often accumulations of fibrous or acicular mineral forms, creating a satin-like texture (some forms of gypsum do this). “Dull” luster looks dull. “Earthy” luster looks like compressed dirt. Taken together, these lusters represent the vast majority of minerals in a typical collection.

Results

Scan results are tabulated below by luster and surface complexity. Surface complexity exhibited some control on how easily minerals scanned: high -complexity surfaces were more difficult to scan (Table 1). Similarly, the combination of colour and shine was important: the easiest minerals to scan were dull; the hardest to scan were dark and shiny (Table 1).

“Shiny,” though, was a more complex variable than “shiny” vs. “dull.” Some “shiny” lusters scanned easily (e.g., metallic, submetallic, pearly, silky), while others did not (e.g., adamantine, waxy, greasy, vitreous; Table 2).

Time requirements

Each full-resolution scan scan (of full-turns, at 32 steps) required about 15 minutes; however, most specimens required more than one scan. Specimens with dull lusters required the fewest scans; shinier specimens required more. The dull Sandy Topaz BMC-V5847, for example, required only one scan; the shiny Garnet BMC-V5488 required five.

After each scan, approximately 5 minutes of additional editing/optimization was required for simple specimens. More was required for specimens that had abnormalities in their scans. For example, the Native Silver BMC-V0455 moved slightly during one scan, producing a second tendril of silver; this had to be edited out.

After editing, each specimen required an additional 5-10 minutes to convert to a watertight mesh object.

In all, then, each specimen required somewhere between 25 and 100 minutes to produce a digital 3D object.

Table 1. Tone and shine vs. surface complexity.
(S) indicates a mineral was successfully scanned
(F) indicates a mineral that failed to be scanned, even with workarounds summarized in the Conclusions section
** indicates a mineral that failed to scan naturally, but scanned successfully once cornstarch was applied*
– indicates a mineral that failed to scan naturally, and failed to scan with cornstarch

	High Complexity	**Medium Complexity**	**Low Complexity**
Success:	**63%**	**93%**	**94%**
Light & Shiny - 67% success rate	**Wulfenite BMC-V8722 (F)** **Zeolite BMC-V6329 (F)** **Mica BMC-V6788 (F)** Selenite BMC-V8443 (S) Calcite Stalactite BMC-V3489 (S) Mimetite AA343 (S)	**Wavellite BMC-V7827(F)** Copper BMC-V543 (S) Emeralds BMC-V5096 (S) Rand Calcite Pearls (S)	**Quartz BMC-V2276 (F–)** Microcline BMC-V4644 (S) Quartz BMC-V2502 (S) Pyrite BMC-V1110 (S) Wavellite BMC-V7841 (S)
Dark & Shiny 55% success rate	**Pyroxene BMC-V4888 (F)** **Galena BMC-V0769 (F)** Hematite Rose BMC-V2096 (S)	**Goethite BMC-V3198 (F*)** **Sphalerite BMC-V0846 (F)** Stibnite BMC-V0641 (S) Staurolite BMC-V6943 (S)	**Cassiterite BMC-A244 (F)** Hauerite BMC-V1298 (S) Garnet and Mica BMC-V5486 (S) Wurtzite BMC-V0958 (S)
Light & Dull - 93% success rate	**Wulfenite BMC-V8702 (F)** Quartz ps Calcite BMC-V2730 (S) Wurtzite BMC-V0958 - dull component (S) Bayldonite BMC-V7810 (S)	Stilbite BMC-V6541 (S) Quartz ps. Anhy. BMC-V2719 (S) Aragonite Rose BMC-V4055 (S) Zeolite BMC-V6662 (S)	Rhodonite (S) Topaz BMC-V5847(S) Malachite ps. Cuprite BMC-V1942 (S) Leucite BMC-V4792 (S) Quartz ps. anhydrite BMC-V2719 (S) Kaolinite ps. Feldspar BMC-V4596 (S)
Dark & Dull 100% success rate	Native Silver BMC-V0455 (S) Native Silver BMC-V0439 (S) Goethite BMC-V3199 (S)	Ilvaite BMC-V6074 (S) Conichalcite BMC-V7801 (S) Native Copper BMC-V5047 (S)	Staurolite BMC-V6344 (S) Vivianite BMC-V7724 (S) Lava Stalactite BMC-V4820 (S)

Time requirements for 3D printing varied by the size of the objects. Native Copper BMC-V0543 measured about 2 x 1 inches, and required about 2.5 hours to print. Goethite measured 3.5 x 4.5 inches and required 22 hours to print. These time estimates change as a function of wall thickness as well.

Discussion

The aims of this project were to analyze the variables that affect 3D scanning and 3D printing of mineral specimens, to develop ideal specimen criteria for structured light scanning, and to establish work-arounds for non-ideal mineral specimens.

Mineral opacity is most important of the variables involved; transparent materials do not scan with structured light scanners. The opacity issue means even minerals with very faint translucency often fail to scan. Even minerals with slightly translucent components fail to scan those areas. For example, the Quartz after Calcite BMC-V2276 reported here had a section of slightly transparent crystals at its base; these failed to scan, regardless of lighting conditions (Figure 1). The digital 3D mesh modeling was able to interpolate over the missing sections, so the scan was still successful, but only because the areas in question were on the bottom of the specimen. Zeolite BMC-V6329 was judged opaque upon visual inspection (Figure 2A), but was completely invisible to the scanner. Workarounds to opacity are discussed at the end of this article.

Table 2. Lustres
** indicates a specimen that failed to scan naturally, but successfully scanned once cornstarch was applied.*
– indicates a mineral that failed to scan naturally, and failed to scan with cornstarch.

Luster	Success	Successful Scan	Failed Scan
Adamantine	0%		Wulfenite BMC-V8722 Titanite BMC-V7033 - adamantine parts Vivianite BMC-V7724 - adamantine face Mica BMC-V6788 - adamantine faces
Waxy	**33%**	**Wavellite BMC-V7840**	Goethite* V3198 Cassiterite A244
Greasy	**50%**	**Calcite Stalactite BMC-V3489** **Mimetite BMC-AA343**	Wavellite BMC-V7827 Zeolite BMC-V6329
Vitreous	**50%**	**Garnet component on BMC-V5486** **Microcline BMC-V4644**	Quartz¯ BMC-V2276 Pyroxene BMC-V4888
Resinous	**67%**	**Emerald BMC-V5096** **Titanite BMC-V7033 - the resinous parts**	Sphalerite BMC-V0846
Metallic	**80%**	**Hauerite BMC-V1298** **Stibnite BMC-V0641** **Pyrite BMC-V1110** **Hematite Rose BMC-V2096**	Galena BMC-V0769
Submetallic	**100%**	**Native Copper BMC-V0543** **Native Silver BMC-V0439** **Ilvaite BMC-V6074** **Wurtzite BMC-V0958** **Native Copper BMC-V5047**	
Pearly	**100%**	**Mica component on BMC-V5486** **BMC-Rand Calcite Pearls** **Quartz BMC-V2502** **Staurolite BMC-V6943**	
Silky	**100%**	**Selenite BMC-V8443** **Zeolite BMC-V6662** **Wavellite BMC-V7841**	
Dull	**100%**	**Native Silver BMC-V0455** **Malachite after Cuprite BMC-V1942** **Quartz after Anhydrite BMC-V2719** **Quartz after Calcite BMC-V2730** **Leucite BMC-V4792** **Sandy Topaz BMC-V5847** **Vivianite BMC-V7724 - the dull faces** **Staurolite BMC-V6344** **Stilbite BMC-V6541** **Wurtzite BMC-V0958 - dull component**	
Earthy	**100%**	**Aragonite Rose BMC-V4055** **Conichalcite BMC-V7801** **Goethite BMC-V3199** **Bayldonite BMC-V7810** **Kaolinite ps. Feldspar BMC-V4596** **Native Copper BMC-V5047 - earthy parts** **Lava Stalactite BMC-V4820**	

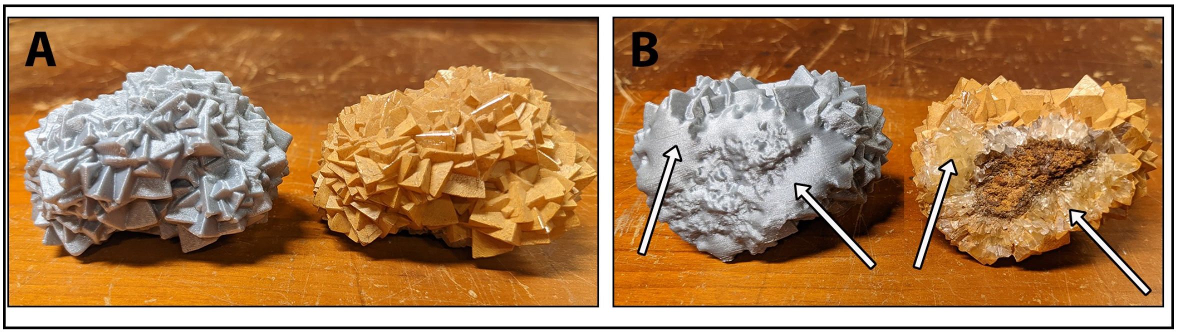

Figure 1. Quartz after Calcite BMC-V2276. A) 3D print of specimen (left) vs. actual specimen (right). The scanner and printer have reproduced the complex crystal surface well. B) Bottom of specimen. Arrows point to areas of translucence on the original specimen, which the scanner has failed to reproduce. The mesh-making software interpolated across those areas, producing smoothed zones.

The second most important variable was surface complexity: only about 63% of the minerals examined here with high surface complexity successfully scanned. The biggest issue was overhang. The Wulfenite BMC-V8702 specimen, for example, failed to scan because its two overlapping tablet-shaped crystals produced an internal cavity invisible to the scanner (Figure 2B). The BMC-V8443 Selenite specimen had several cavities where knots of fibers curled over themselves; these also failed to scan, although the mesh modeling's interpolation produced a passable 3D object, even though some detail was lost.

Mineral luster was also important in determining whether a mineral scanned, though this is a more complex variable. Dull and earthy minerals scanned consistently well; though these rarely present crystal forms that are interesting as 3D objects.

Minerals with some degree of "shine" were more complicated: In general, minerals with high shine did not scan well. For example, the adamantine Wulfenite BMC-V8722 failed to scan, as did the adamantine surfaces on Vivanite BMC-V7724, Titanite BMC-V7033, and Mica BMC-V6788 (Figure 2C). Specifically, the components that failed to scan were the highly-reflective crystal faces. Presumably, this is because the highly-reflective faces saturate the scanner's receptors. To a certain extent, this can be compensated for by reducing the lighting on the specimen. For example, the shiny vitreous garnet in BMC-V5486 eventually scanned at a lower light setting (see Workarounds section below); however, for dark and shiny minerals, this renders them invisible. This is why dark and shiny minerals had the lowest rate of success in scanning.

For other specimens, however, their shininess was a more nuanced variable. For example, Goethite BMC-V3198 and Stibnite BMC-V0641 are both gunmetal-gray specimens, both shiny, and both have medium surface complexity (the Goethite has smooth botryoidal curves that divot into crevices, while the Stibnite has long, often deep grooves

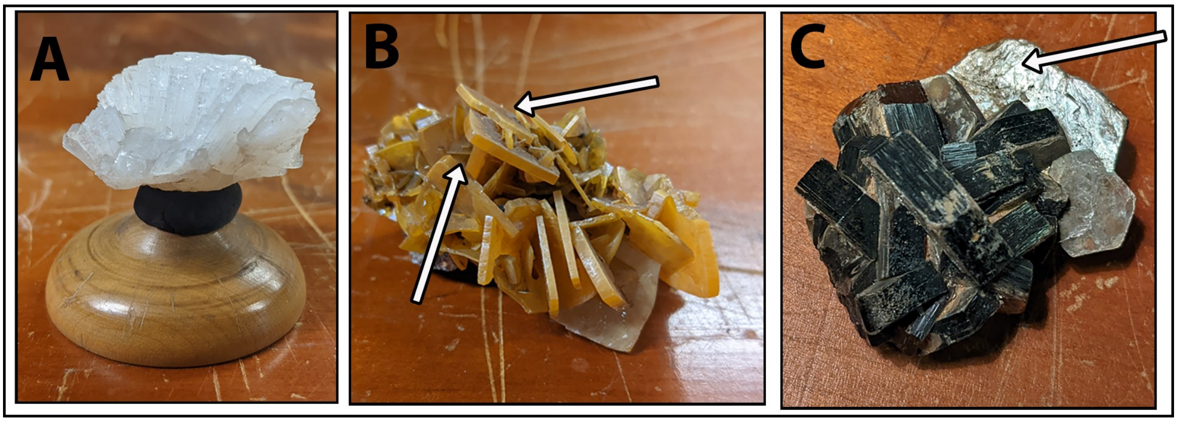

Figure 2. Failures. A) Zeolite BMC-V6329 appeared opaque, but was translucent enough to be invisible to the scanner. B) Wulfenite BMC-V8702 had two overlapping crystals (arrows) that created a hidden space inside. This was invisible to the scanner and could not be duplicated. C) Mica BMC-V6788 had high-shine cleavage planes (arrow) that were invisible to the scanner.

running its length). Yet the Goethite failed to scan without cornstarch application (see Workarounds below), and the Stibnite succeeded. It is possible this was due to differences in their specific shininess (Goethite was waxy, Stibnite metallic), or a function of both shine and morphology (Figure 3).

In general, greasy, waxy, and vitreous minerals were problematic to scan, though other shiny lusters were usually successful (e.g., silky, pearly, and metallic). It is possible that greasy and waxy minerals also often accompany convex morphologies that scatter higher percentages of light away from the scanner than flat crystal faces. For vitreous minerals, it is possible their difficulty in scanning could arise from lingering translucency, even if they appear opaque in hand sample.

Alternative technologies

This project used a structured light scanner that is within the budget and space constraints of a university collection; however, it is likely that a laser scanner would react similarly to the surfaces reported here. Laser scanners, though, might have more trouble with high-scatter surfaces (for example, minerals with complex topographies), and abrupt changes in surface topographies (Cieslik and Harris 2020, p. 16). Both high-scatter surfaces and abrupt surface topography changes are common in mineral specimens. Still, a future comparison between structured light and laser scanners would be useful.

Conclusions

Below, we outline the characteristics of an ideal mineral specimen for structured light 3D scanning 3D and printing, and workarounds for non-ideal candidates.

Ideal properties for 3D scanning and 3D printing

- **Opaque.** Transparent or translucent specimens are inappropriate for reflective scanning. They are invisible to the scanner. *Possible workarounds*: cornstarch application described below. Minerals that are only faintly translucent (e.g., BMC-V4088 Aragonite reported here) might still scan if given very high illumination during scanning.

- **No overhangs.** If a specimen has overlapping surfaces, the scanner will find it very difficult to scan. Wulfenite BMC-V8702 reported here was unable to be scanned because two of the large crystals pointed toward each other, creating a hidden internal space that the scanner could not access. Aragonite BMC-V4083 reported here had multiple overlapping tendrils. The scanner was able to accommodate enough of them that the scan could still produce a successful replica; however, the details of areas between the tendrils were lost.

- **A distinctive form or habit.** For specimens bound for 3D printing, the core property being replicated is form. For example: the Sand Topaz

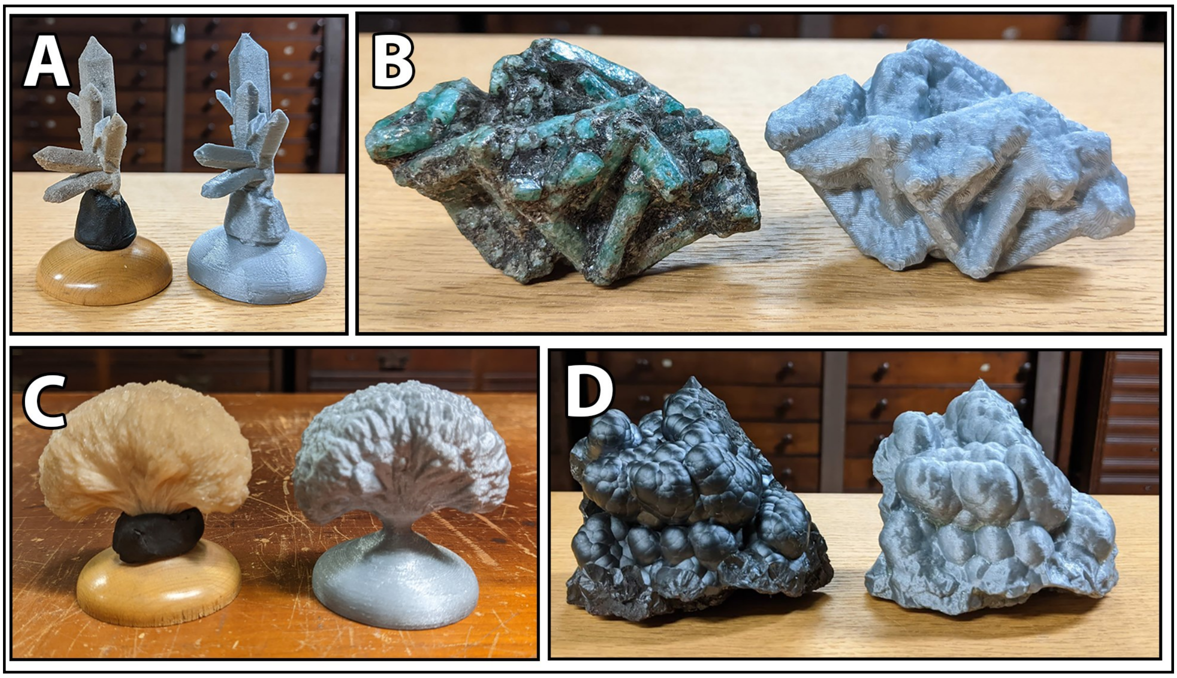

Figure 3. Successful reproductions. A) Sand Topaz BMC-V5847, B) Emeralds BMC-V5096, C) Stilbite BMC-V6541, D) Goethite BMC-V3198.

BMC-V5847 reported here was successful because it had a distinctive crystal form, independent of its colouration. (Figure 3A). Poor candidates would be ones whose most obvious characteristics are in colouring (e.g., banded agate) or a mineral in massive habit, though these might still produce interesting 3D objects that could be viewed digitally.

- **Topographic prominence**. For 3D printing, ideally, a specimen stands up above its surroundings. For example: the Sand Topaz BMC-V5847 reported here was a single prism of crystal, with several smaller prisms radiating away from its base. Poor candidates have all the details collapsed onto a single surface. For example: the Emeralds BMC-V5096 reported here were visually confusing once 3D printed, because the overlapping columns were all on the same plane (Figure 3B). The result was a lumpy-looking rock-shaped object that lacked distinctive crystal form. Similarly, the Wavellite BMC-V7841 reported here had radiating fibers. Although the scanner showed that level of detail, they were all collapsed onto a single surface and less interesting as a 3D form. Flat specimens might still produce interesting 3D digital objects, just not for 3D printing.

- **Light colour.** Structured 3D scanners pick up light colours more easily, though dark coloured minerals can be scanned as long as they have a duller luster. If a specimen has both light- and dark-coloured components, multiple scans at different illuminations are required. *Possible work-around*: multiple scans at higher illumination, and/or cornstarch (see below). For dark minerals with shiny luster, multiple scans can work, but it is time-consuming; the Hematite Rose (BMC-V2096) required 21 scans.

- **Not shiny luster.** Dull or earthy lusters are ideal for structured light 3D scanning; all our dull/earthy specimens were successfully scanned. The scanner was more inconsistent with shiny specimens. In general, the duller the luster, the better.

- **Not bendable or morphable**. This is unlikely to be a common problem with minerals; however, specimens should not change shape during scanning. For example, the Native Silver BMC-V0455 reported here had a long tendril extending beyond its main form. During one scan, the tendril moved slightly relative to the rest of the specimen; in that scan, it appeared as a *second* tendril and required manual editing of the 3D object to fix. Additionally, the Stibnite BMC-V0641 reported here is attached to a wooden stand by a piece of putty. During one scan, the putty deformed a little, causing the angle between the crystal and the stand to change slightly; this scan had to be deleted and re-done.

- **A size appropriate to the scanner**. The EinScan used here lists its minimum specimen size as 30x30x30 mm, though the smallest specimen successfully scanned here was 15x15x15 mm.

Workarounds for non-ideal candidates
Despite the limitations, most of the minerals tested for scanning here did successfully scan – eventually, but several required work-arounds:

- **Adjusting the angles:** Multiple scans at varying angles was helpful for many specimens, especially those with overly shiny lusters and complex surface geometries.

- **Opacity:** For translucent or transparent minerals, applying cornstarch or a similar spray-whitener to the surface can produce a scan (see discussion below). For only slightly-translucent minerals, setting the scanner to high illumination can also produce workable results (for example, BMC-V4088 Aragonite reported here). If the specimen is easy to clean without damaging it, a light sheen of cornstarch can be applied to reduce shininess (this does affect the 3D object, which no longer reproduces the specimen's texture). Ideal candidates for this would be sturdy enough to be cleaned afterward, without fine detail that could get gummed up or damaged by the cornstarch. For some specimens, the cornstarch has trouble adhering to the surface, e.g., the Quartz BMC-V2276 specimen reported here, whose scan failed even with cornstarch. It is recommended the cornstarch be applied using an air-puffer or flour sifter, which precipitates a fine-grained, even "snow" of cornstarch onto the specimen. This is preferable to "painting" the cornstarch on with a paintbrush or shaking unsieved cornstarch onto it, both of which result in uneven distributions. Cornstarch can be removed with a paintbrush, sponge, or (if the specimen is exceedingly sturdy) washing it off with water. It is important to completely remove all cornstarch from specimens, because it could attract pests. Also, water should never be applied to specimens that may contain pyrite.

- **Overhangs**: It can help to perform multiple scans at a variety of angles; however, even with systematic repositioning, some overlapping surfaces are too complex for a desktop scanner.

- **Dark colour:** For dark-coloured minerals, increasing the brightness of the illumination can help. For specimens with both dark and light components, a scan at high-lighting can catch the dark materials, followed by a scan at lower lighting for the light minerals.

- **Shiny luster**: Shiny specimens can be scanned by lowering the illumination and/or performing multiple scans at a variety of angles (to change the surfaces producing strong reflections). The resinous emeralds reported here, for example, required five scans to successfully complete (compared to dull minerals, which typically required only 2 scans).

  However, for specimens that are both dark in colour *and* shiny in luster, lowering the illumination to prevent shininess has the effect of making the dark-coloured mineral invisible. Hematite Rose BMC-V2096 reported here required 21 scans of various brightnesses and at different angles to capture *most* of the metallic luster of the tablet-shaped plates (compared to 1 or 2 scans for light -coloured, dull-lustered minerals).

- **Cornstarch**: If the specimen is easy to clean without damaging it, a light sheen of cornstarch can be applied to reduce shininess (this does affect the 3D object, which no longer reproduces the specimen's texture). Ideal candidates for this would be sturdy enough to be cleaned afterward, without fine detail that could get gummed up or damaged by the cornstarch. For some specimens, the cornstarch has trouble adhering to the surface, e.g., the Quartz BMC-V2276 specimen reported here, whose scan failed even with cornstarch.
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- **Scanning fragile or small minerals**: Because the scanner cannot see translucent materials, and struggles with very dark materials, it is easy to prop small or fragile specimens on glass or dark holders. The holders aren't scanned, and the specimens can be more delicately placed.

- **3D Printing fragile specimens**: specimens with fragile, thin extruding components can be reinforced by thickening the walls of the 3D print. For example, Native Silver BMC-V0455 reported here has two long, fragile tendrils protruding from the specimen. Increasing the thickness of the 3D print walls from 1 to 3 mm strengthened it considerably; however, in the initial 3D print, one of the tendrils still snapped off.

Mineral species that meet criteria for successful scanning

Though the properties described above rule out a percentage of mineral specimens, there are several mineral groups that frequently have the properties needed for a successful scan.

- **Native Element class minerals (like Gold, Silver, or Copper)** often present interesting mineral forms, opaque surfaces, and lusters needed for successful scans, though exceptionally metallic lusters might require a higher numbers of scans. Dendritic forms can be particularly interesting as 3D digital or 3D printed objects.

- **Oxide class minerals (like Hematite, Goethite, or Magnetite)** are similarly well-suited for scanning. Botryoidal and octahedral habits, for example, are visually interesting and often replicable.

- **Clay group minerals (like Kaolinite)** are ideal candidates for 3D scanning, except for their unfortunate tendency to be boring: they tend to massive habits that do not inspire form replication. However, when clays pseudomorphs into more interesting forms, they can make excellent candidates for 3D scanning. For example, kaolinised Orthoclase crystals make for easy scans and interesting forms (e.g., Kaolinite ps. Feldspar BMC-V4596 reported here).

- **Zeolite group minerals (like Stilbite)** often have light colour, dull luster, and interesting radiating habits.

- **Staurolite** and **Rhodonite** often have luster and form conducive for 3D scanning and 3D printing.

- **Pseudormophed minerals** in general are often good candidates: a high percentage of the minerals successfully scanned here are pseudomorphs. Presumably this is because high-shine lusters are not preserved under conditions where mineral replacement is occurring.

Unfortunately, a large percentage of the most common minerals are more difficult – or impossible – to scan: quartz and calcite, for example, are usually transparent or translucent enough to be invisible to a scanner (though there are opaque exceptions). The feldspars, olivine, and the pyroxenes rarely present forms interesting in 3D replication. Amphiboles and micas are often too dark and shiny.

The core conclusion from this project is that only a subset of mineral specimens are appropriate for 3D scanning and 3D printing using technology currently available at the university level. However, that subset is not zero, and the specimens that are appropriate for 3D scanning and 3D printing can produce exciting results. Additionally, many specimens that are not ideal candidates can still be scanned if time is available to devote to the process.

Future work could involve comparisons of different types of 3D scanners. For example, photogrammetry might be a more effective way of building digital 3D models of transparent minerals, as the photographer could control the component 2D images. Additionally, although laser scanners are expected to have similar limitations to structured light scanners, a comparison would be interesting.

One additional issue arising from this work is replication of surface complexity. Many specimens showed a loss of detail, probably during the 3D printing process. Further exploration of detail replication would be interesting, perhaps by systematically varying 3D printing settings, materials, or 3D printer types.

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One Earth one future: A new approach to inspiring biodiversity, through artwork, digital technology and museum specimens

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Abstract

21st century technology offers a powerful way to virtually explore the great diversity of habitats and landscapes of our planet, including its most remote regions. However, natural science collections provide a unique connection to the organisms themselves that live within those habitats and complex ecosystems. This paper describes a novel approach through using a combination of collections, digital technology and artwork to inspire an understanding of biodiversity, and in particular pollinators such as bees. We worked with Suffolk Family Carers clients, aged 9-12. We explored a range of habitats using satellite images, focusing on the local agricultural landscapes of Suffolk and which aspects of these environments would be most conducive to bee diversity. The young people created individual two-dimensional artworks and then a three-dimensional group artwork of their ideal bee environment. Much of their understanding of the key concept, biodiversity, however, seemed to stem from their physical experience through the main natural science gallery where they could explore the diversity of nature through taxonomic and diorama displays. This study highlights that even though digital technology offers a powerful vehicle for engaging young people, we should not forget the importance of using museum specimens to connect with the natural world.

Keywords: Collections, specimens, biodiversity, digital, satellite, bees, artwork, community, co-creation

Introduction

Just over 50 years ago, the Apollo Moon missions allowed humanity to see our home, Earth, for the first time as a fragile blue planet, surrounded by the vast blackness of space (Our Planet, 2019). Since this time, our detrimental impacts on the planet through habitat loss, pollution, introduction of invasive species and climate change have become incontrovertible through multiple lines of evidence, including recent IPCC reports (e.g. Pörtner *et al*., 2002) and being able to visually see signs of environmental changes from space. An unprecedented task lies ahead in not only mitigating these impacts but also reversing them to save our natural world.

Museums constitute a wide network across many regions of the world and are ideally situated to help promote an awareness of environmental sustainability, and more specifically they can help to achieve the UN's Transforming Our World: the 2030 Agenda for Sustainable Development (United Nations, 2015). This role was recognised in the

2019 ICOM Kyoto meeting "Curating Sustainable Futures". In order to achieve a more sustainable planet, through for instance engaging the public in initiatives around environmental protection, it was recommended that museums must draw on their unique collections and work with local and global communities to foster community engagement and education to explore and proactively generate a sustainable future (ICOM, 2019).

To date, museums have communicated on these topics through exhibitions - for example, Wade (2022) explores a novel way of using the display of contemporary art in natural history collections to engage audiences about the environmental crisis, and also talks, workshops and other engagement activities - for instance, Freedman *et al.* (2010) detailed how during a science week, visitors investigated the miniature world of oceans using live specimens under a microscope and models of plankton. Digital technology is a more recent form of engagement which museums are using to reach new audiences, including younger people (e.g. Mujtaba *et al*., 2018, Jackson, 2020). This project reports a novel approach to using digital technology, namely satellite images, to develop an understanding of biodiversity, and as inspiration for 2D and 3D artworks in a museum setting. The NHM has displayed a huge, 7 m diameter 3D Earth artwork created from detailed NASA images of our planet taken from space (Zhongming, 2018) but in our project we are using satellite images as an inspiration for the artworks rather than as part of the artworks directly. Also, the project Inspace (University of Edinburgh), have announced 5 artists in residence who will be focusing on the theme of Space and Satellites data. For example, one of the artists is using remote sensing data from Scottish wildlife conservation organisations to use animals' movements as a source of inspiration for various artworks. However, the novel approach of our project is that it took place within the museum environment, using collections to provide a key role in underpinning the understanding of biodiversity.

Rationale and background to the project

Ipswich Museum audience surveys (Mather *et al*., 2021) demonstrate that people who visit this Museum are interested in biodiversity and environmental sustainability. However, participants are unable to clearly articulate why. This project introduced themes around biodiversity in a non-scientific way, framed through artistic and creative activities, to convey key concepts more simply.

It was decided from the outset that we would use digital technology and in particular satellite images to inspire the artworks. The use of data from digital satellites can help to further our understanding of Earth's changing complex environments and ecosystems. Specifically, Satellite Remote Sensing (SRS) permits researchers to address questions on scales inaccessible to ground-based methods alone, providing variable information on long-term-trends in biodiversity observing large-scale areas (Pettorelli *et al*., 2014). This includes, for instance, monitoring species distributions such as mapping wildlife in open savannas to estimate population size, being less "invasive", time-consuming, costly and labour-intensive compared to more traditional surveying methods (Zheng, 2012). Satellite images can also be used to study human-induced changes to landscapes such as deforestation, and can be combined with powerful "deep learning" algorithms to more accurately estimate the extent of deforestation (Lee *et al*., 2020). This powerful technology also provides an excellent means to communicate concepts of biodiversity and to quickly navigate, observe and study even the most remote places on the planet using satellite images. The variety of different habitats and ecosystems across the globe, and shapes, forms and colours, from which they are composed, provides an almost infinite source of inspiration for artworks, changing at the height the "observer" views Earth from space. A key benefit of this technology is that it is visual so that the viewer can immediately see any changes to landscapes over time, which can then have a big impact on their understanding of biodiversity, which could even change the way they think about their own lifestyles.

The Museum selected the charity Suffolk Family Carers (SFC) to collaborate with on this community project. For 30 years, SFC has assisted family carers of all ages across Suffolk to get the support they need to live fuller lives. As the Museum has an established relationship with this charity, this made it an ideal group to try out this new project. Previously, the Museum has collaborated with SFC to co-create events that explore Black history and African cultures, offered respite activities inspired by Ipswich Museum's collections, and provided venues for regular SFC club meet-ups.

The aims and objectives of the project were then developed in discussions between the Museum and SFC and then, after funding had been secured, a freelance artist with a specialism in biodiversity was sought out, using a known network of existing contacts.

The Museum recruited installation artist and contemporary composer, Lily Hunter Green (LHG). LHG has extensive experience of making artworks around bees, for example, converting redundant pianos into working beehives (Green, 2014). This led to the project's focus on bees and discussions around pollinators more generally. With their vital role in maintaining healthy ecosystems for global food security, with crops pollinated by bees contributing to about one third of total human food (Khalifa *et al*., 2021), it makes them an ideal 'flagship' group of species to communicate principles of biodiversity.

The workshop content was then finalised in discussion between the Museum and LHG, and SFC were consulted throughout the process. LHG had a certain amount of flexibility in how these workshops could be delivered and the type of artworks which could be done, but working within the framework of the aims and objectives i.e. using satellite technology to inspire the artworks.

The workshops

Two workshops were delivered at the Museum, led by two Ipswich Museum Collections and Learning Curators (SJ and Eleanor Root) with LHG for a group of nine young people aged 9-12 from SFC. These were delivered within a dedicated education room, allocated for school groups and community groups. Each workshop was 2 hours in length although it included breaks for the young people.

The purpose of the first workshop was to introduce the young people to the concept of biodiversity and why it is important. This was achieved through watching a short 5 minute Sir David Attenborough video (Attenborough, 2021) followed by a question and answer session. The group was then taken to the Victorian Natural History Gallery where they explored concepts of biodiversity, referring to the natural science displays. These Victorian displays consist mainly of specimens in display cabinets stretching around the galleries with invertebrates, fish, reptiles and mammals arranged clockwise respectively, reflecting the progressive nature of how the Victorians saw the natural world and tried to make sense of it (Figure 1). The middle of the gallery is occupied by cased and un-cased large mammal taxidermy including the Museum's iconic Rosie the Rhino - which featured in Rowland Ward's 'Records of Big Game' in 1903 and had the second largest horn of any Indian rhino shot at that time - and French explorer Paul du Chaillu's gorillas. This gorilla group was shot around 1862 and was part of the first group of gorilla specimens seen in Britain. A large cabinet, at the back, includes a set-piece collection of African mammal taxidermy.

The young people were encouraged to look closely at the objects and choose their favourite, and in so doing encountering a vast number of species across the animal kingdom. During this part of the

Figure 1. Photograph of Victorian Natural History Gallery, reflecting the gallery prior to the museum redevelopment 2022-25 showing taxonomic arrangement of cases around central cases and exhibits. © Colchester and Ipswich Museums.

Figure 2. A key part of the young people's learning about biodiversity was through the Victorian Natural History Gallery's displays. Display case shown prior to the museum development 2022-25 . © Colchester and Ipswich Museums.

workshop it was noted that some of the young people displayed curiosity to the various displays particularly with regard to the diversity of species (Figure 2). Some were also drawn to the Victorian depictions of animals, such as the group of gorillas and it was explained to those enquiring that this is how Victorians saw them at the time. Some of these displays will remain as key objects in the Museum's redevelopment and will be central to discussions around collecting practice and decolonisation. At the end of the exploration, there was a follow-up discussion to reflect on the range of animals they had seen and why biodiversity in nature was important.

The next phase of the workshop introduced the group to how we can explore biodiversity through digital technology and was facilitated by the freelancer, LHG. We focused on how we can use satellite technology to explore different habitats from space using Google Earth. Google Earth allowed the young people to easily explore areas of interest through the search function. The Geographic Information System (GIS) - a computer system that captures, analyses and displays information attached to unique geographically referenced locations or sites - data means that names of various sites can be easily identified just by clicking on areas of interest. Firstly, we looked on a global scale at the importance of rainforests and the group virtually explored the Amazon rainforest, including its vastness, drawing attention to the variety of tree types evident from the pictures.

Whilst it was important to communicate the importance of biodiversity on a global scale, it was invaluable to bring the subject to the local scale and environments which the young people could see in Suffolk. LHG showed the group satellite images of local agricultural habitats, drawing attention to the patchwork quilt-like nature of the landscape. The main objective was to communicate which of these habitats, used for agriculture, were most conducive to pollinators such as bees. For instance, LHG drew attention to the function of hedgerows as wildlife corridors, wildflower strips around fields for foraging, and the presence of water for drinking. This information would be the basis of the later artworks. As recorded in the evaluation, the young people were surprised by the varied colours of the landscapes and by the importance of local pollinators including the fact that bees need different species of flowers for foraging. LHG expanded on this discussing the vital role that bees have in pollination, providing food for other animals including ourselves. The workshop culminated with the group of young people creating individual drawings of their ideal environments for bee diversity, consolidating their learning from the satellite images (Figure 3).

The second workshop took place a week later and started with a summary of the importance of biodiversity and ecology. The group then worked together to create a 'bee-friendly' 3D landscape, using recycled materials such as redundant carpet tiles, old pieces of clothing and recycled coloured paper. The young people were encouraged to use

Figure 3. The young people created their own individual two-dimensional drawings of their ideal bee habitats, based on agricultural landscapes in Suffolk reproduced with permission of Suffolk Family Carers .
© Colchester and Ipswich Museums.

their artworks from session one as inspiration for the 3D landscape although this led them to work individually rather than as a group (Figure 4). To encourage collaboration, young people were delegated particular responsibilities e.g. one young person encouraged to recreate water, another hedgerows, which facilitated more effective group working.

LHG created a 3D virtual model of the reimagined landscape designed by the group - a digital output which could find its way into a future Museum display. A flying drone was flown over the artwork, creating aerial photographs from several different views. 3D models were created using photogrammetry, which involves taking overlapping photos of an environment and converting them into a 3D model using algorithms on a computer or tablet. The 3D models were actually made during the workshop and processed on the tablet - some of the group even had a turn at taking some of the pictures which were stitched into the model (Figure 5).

The second workshop culminated in a short presentation from SJ about some of the actions that we can take to preserve biodiversity and mitigate climate change. Young people created individual environmental pledges that they would take home with them, for instance, walking to school or eating less meat The creativity and thoughtfulness seen in the pledges demonstrated

Figure 4. The young people worked as a group to create a three-dimensional artwork of their ideal bee habitats based on local agricultural landscapes reproduced *with permission of Suffolk Family Carers.*
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Figure 5. 3D model of the young people's collective artwork created by artist, Lily Hunter Green.

that the young people want to make a difference in preserving biodiversity and tackling climate change (although being aged 9-12 meant that they would have had limited control over their lifestyles and diets).

Results

To capture learning from the group of young people, a Microsoft Forms survey was completed before and after the two workshops (see Appendix I), which asked them what they knew about biodiversity and climate change and to reflect on their learning. The survey consisted of seven questions with five possible responses arranged in a Likert scale, e.g. from "not important at all" to "of extreme importance".

There was a considerable increase in knowledge around biodiversity and environmental sustainability. For instance, when asked 'How much do you know about looking after your planet?', the combined responses "a lot" and "a huge amount" increased from 17.6% to 78% before and after the workshops, respectively.

Another significant increase was around knowledge of the use of satellite images for looking after our planet. For instance, in response to 'How much do you know about using satellite images to study this topic?' none of the young people selected "a lot" or "a huge amount" before the workshops. After the workshops, the combined response in these categories was 22.2%. Moderate understanding increased from 29.4% to 66.7% before and afterwards.

However, in response to the first question "How important is looking after the planet?" the number of responses in the "extreme importance" category decreased slightly from 64.7% to 55.6% although responses in the "very important" category increased a little from 29.4% to 33.3%. This might may be caused by little subjective variation between the two surveys.

The survey results demonstrate success of the study in communicating the importance of bees as pollinators. In response to "Is there anything about the environment that now particularly concerns you?" before the workshops, participants answered with responses including: animals, Earth and climate change. Understandably, after the second workshop 33% answered with responses that included bees or other pollinators.

The young people's enthusiasm increased after the exploration of the Victorian Natural History Gallery, although this was not quantitatively measured. However, at the end of the workshops their enthusiasm for biodiversity and the environment was demonstrated by the majority (7) of the young people engaging with the "make a pledge activity" to create a variety of actions (Appendix II).

Conclusions

This project was undertaken as a funded pilot project and, so therefore, the number of sessions was limited. As discussed above in the rationale section, we chose to work with a community group that we had an established relationship with but following the success of the project there is no reason why the project cannot be expanded on for other age groups and community groups. For the particular format of the sessions, the size of the group (9 young people) seemed to be an optimum number - fewer would have reduced the "buzz" of enthusiasm with the group and more would have been harder to manage in the workspaces selected.

In formulating the project, including its aims and objectives, it proved invaluable to bring on board the proposed community group that we intended to work with from the outset. This meant that the content would sufficiently meet the needs of their clients, the young people. The project worked well in combining both the in-house expertise through the experience of the Collections and Learning Curators, with the more specialist knowledge and artistic abilities of the freelancer, LHG. This multi-disciplinary approach enabled a degree of depth which the project would not have otherwise had.

The different elements to the project: collections, 2D and 3D physical artworks, digital technology including the 3D modelling, and environmental pledges (Appendix II) over the 2 workshops proved a successful way of keeping the young people engaged and maintaining their focus and enthusiasm. The artworks proved to be successful in their combination of individual 2D creations followed by a collaborative effort to create the 3D artwork. Splitting the content over two two-hour workshops, with only a week in between also proved to be effective and allowed the young people to reflect on their knowledge and learning between the workshops and at the start of the second workshop.

The results clearly show that the project successfully engaged the audience, measured through increased understanding around biodiversity and the use of satellite technology to study the topic. Most of the young people made pledges to preserve biodiversity or mitigate climate change, which demonstrates their concern for the environment.

Biodiversity is a complex topic to communicate, however. The physical journey through the Victorian Natural History Gallery allowed the young people to grasp the enormity of biodiversity. The Museum used its displays to provide a connection with the natural world, something which videos and images would not have been able to reproduce so successfully. Whilst the taxonomic arrangement of objects around the sides of the gallery allowed the young people to understand the variety of life and how species are classified into different groups, the dioramas allowed them to visualise the animals in their natural habitats as part of complex ecosystems. Their enthusiasm and vibrance was considerably greater after the gallery exercise had been completed. Therefore, if the session was repeated in the future, starting with the physical gallery exercise might prove a more efficient way of gauging their interest from the outset. The exercises in the gallery could also be expanded slightly and also undertaken at the beginning of the second workshop. Gallery exercises would, however, need to be modified slightly in line with the modifications to the gallery as part of the Museum's redevelopment project. There was also greater scope for using the collections in addition to just the gallery visit. For instance, the entomology collections could have been used to showcase a large number of bee species to demonstrate biodiversity. These could be made more engaging with the introduction of magnifying glasses for the young people to look through.

The project focused on agricultural landscapes around Suffolk as ideal bee landscapes. It was important to study local landscapes so that the young people could relate to these environments. However, there is a vast potential to digitally explore other habitats both global e.g. Great Barrier Reef or local habitats in East Anglia e.g. the internationally significant Norfolk and Suffolk Broads – indeed, focusing more on local habitats has a greater potential of fostering ownership or environmental stewardship, "looking after our planet". In addition to the satellite images, there is also the potential to enrich the understanding of biodiversity from these landscapes through the natural science collections. For instance, for the reefs, different coral types could be showcased and for the wetland environments, taxidermy vertebrate specimens or entomology specimens could be used. Funding permitting, investigation of the local wetland habitats could also incorporate field-based investigations.

There is also the potential in future workshops for some of the artworks to be displayed in museum displays or on social media. 3D models would lend themselves particularly well to digital displays. This would allow a larger audience to see the work of the community groups.

This project demonstrates a novel way of combining digital technology, artwork and natural science collections to inspire an understanding of biodiversity. It shows that although digital technology is a powerful way of 'exploring' the globe and engaging youngsters, natural science collections have a unique ability to connect with reality and provide a physical journey of exploration. In a digital age, we should not forget the unique selling point of museums, their collections and their power to engage.

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Appendix 1. *Microsoft Forms survey used before and after workshops.*
"Pre" = before workshops, "post" = after workshops. All figures are percentages.
The asterix denotes responses which include concern over bees.

Question	**Not important at all**		**A little important**		**Moderately important**		**Very important**		**Of extreme importance**	
How important is looking after our planet to you?	**Pre** 0	**Post** 0	**Pre** 0	**Post** 0	**Pre** 5.9	**Post** 11.1	**Pre** 29.4	**Post** 33.3	**Pre** 64.7	**Post** 55.6
How much do you know about looking after our planet?	**Pre** 0	**Post** 0	**Pre** 23.5	**Post** 0	**Pre** 58.8	**Post** 22.2	**Pre** 17.6	**Post** 55.6	**Pre** 0	**Post** 22.2
How much do you know about using satellite images to study the topic?	**Pre** 17.6	**Post** 0	**Pre** 52.9	**Post** 11.1	**Pre** 29.4	**Post** 66.7	**Pre** 0	**Post** 11.1	**Pre** 0	**Post** 11.1
Please write below why you think this topic is important	Most common response									
	Pre Planet (47)	**Post** Bees* (33)								
Is there anything about the environment that particularly concerns you?	Most common response									
	Pre Animals (29)	**Post** Bees* (33)								
What experience would you like to get from these workshops?	Most common response									
	Pre Knowledge (19)	**Post** N/A								
Is there anything in particular you have learnt from these workshops?	Most common response									
	Pre N/A	**Post** Bees* (67)								
Is there anything else you would particularly like to learn?	Most common response									
	Pre Planet (23)	**Post** N/A								
Is there anything that surprised you?	Most common response									
	Pre N/A	**Post** Bees* (33)								

Appendix II. *Environmental Pledges Made by the Young People and Staff.*

These pledges have been transcribed as accurately as possible from photographs of pledges (in all but one case which has been interpreted). Names of pledgers have not been included for data protection purposes.

<u>Don't</u> put garbage in the ocean <u>because</u> the world [small picture of Earth] isn't a massive BIN but you are if you put rubbish in the ocean!

I will walk to as many places as I can. I will keep using my reusable thing (bags, bottles) insted [sic] of buying bags and bottle [sic] (one use bottles). I will try buy local food.

I will try to plant more flower [sic] for the bees.

Next year I'll be walking to school and walking back from school so we will sell 1 car out of our 2 cars :-)

The way I will help the environment is by not using my car to go to school but when I have to go far away I can use it but I'll you'se if less [use if less?]. And recycle what I can.

I think that to improve the environment we can all make a difference, but I will try to always bring my metal water bottle.[Water bottle picture]

I already walk to school so therefore I am reduceing [sic] the carbon dioxide by not using a car.
[Car picture].

I have started eating less meat and the other day I made [?]...chill [chilli?] with Quorn insted [sic] of meat.

You should help with pollution (limit ?) and start eating less meat and more vegetables and start riding bikes. [Picture of a bike].
[*The above pledge was interpreted from the original rather than being verbatim due to spelling errors*].

And pledges from the staff:
I will try to buy more food locally.

I will try to always remember my reusable coffee cup [small picture of coffee cup].

I will drive less and walk more.

No Môr Plastic: Museum conservation practise supporting youth led museum environmental activism

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Abstract

Plastic pollution has long been a serious environmental issue, but it is only in recent years we have begun to see a rapid rise in public awareness of the environmental challenges of such pollution. Museums can play a key role in raising awareness of such issues by utilising our collections, spaces, and expertise in novel and creative ways to highlight such environmental issues. In this paper it is shown how static gallery spaces can be utilised in a creative and interventive way by a youth engagement project via their close working with museum conservators and technical staff.

Keywords: Plastic pollution; conservation; exhibitions; engagement

Introduction

Plastic pollution is now so extensive it is having global wide impacts. The United Nations Environment Programme estimates that approximately 7 billion of the 9.2 billion tonnes of plastic produced from 1950-2017 has become plastic waste, ending up in landfills or indiscriminately dumped (Geyer, 2020). Such pollution is not only unsightly but now significantly alters biodiversity, habitats, and natural processes, reducing the ability of ecosystems to adapt to climate change directly affecting millions of people's livelihoods, food production capabilities, social well-being, and human health (Rochman *et al*., 2013; Eriksen *et al*., 2014; Gall and Thompson, 2015). These impacts are also contributing to the overall emotional effects associated with climate change that are rapidly appearing across society (e.g., Doherty and Clayton, 2011; Schwartz *et al*., 2022). Whilst such climate anxiety is driving many people into action, others are experiencing inaction or indecision due to the enormity of the challenge presented by climate change and associated issues. Museums can play a vital role in turning this complex mix of emotions into action and hope (Janes and Grattan, 2019; Sutton, 2020), especially given that museums have a unique place in society and are places trusted by visitors and non-visitors alike (e.g. Dilenschneider, 2020).

Empowering creative youth engagement is increasingly being seen as an important part of supporting the wider engagement of communities across museology and museum outreach in order to drive forward socially engaged museum practice and create a greater societal impact for museums (e.g. Janes and Sandell, 2019). 'No Môr Plastic' (Amgueddfa Cymru, 2018) is a recent example of such a youth led engagement project, led by the Amgueddfa Cymru - Museum Wales Youth Forum (Amgueddfa Cymru, n.d.), and guided by Sarah Younan from the Museum's Learning Department (Younan and Jenkins, 2020). The project focused at looking at the challenge of plastic pollution in the marine environment, and how the marine themed galleries and displays at the Museum could be utilised to highlight this issue. The project title 'No Môr Plastic' was developed as a cultural link being derived from a hybrid of the Welsh and English languages, where the word 'môr' means 'sea' in Welsh giving the 'hashtag' title a take that works well in both languages.

The project was also used as a pilot project for a larger initiative developed by Amgueddfa Cymru called 'Hands on Heritage' (Heritage Fund, 2017), which developed a series of youth led community projects and interventions connecting young people with their history and culture, funded via the National Lottery Heritage Fund's "Kick the Dust" initiative to enable youth-led projects in museums. Projects like this also provide new challenges in developing the way we work, especially in the larger museum institutions as such initiatives need to be faster paced and more reactionary than is usually possible with normal work practises. They are thus an important opportunity to reassess current museum practises to help improve participation and engagement through new innovative approaches.

Conservators and curators play a vitally important role in supporting the development and enabling of such activities through their knowledge of the collections, materials, and the collection spaces we work with. Facilitating such projects and interventions can significantly broaden the remit and impact our collections, and associated spaces can make in supporting a wider awareness on social and environmental issues, further increasing the value of museums to society as a whole (e.g., Machin, 2008; Redler, 2009; Knutson *et al*., 2016).

Development of the Intervention

Initial Concept

The idea for this project arose out of the enhanced public awareness on plastic pollution that followed from the impact of the acclaimed BBC *Blue Planet* documentary series (Males and Van Aelst, 2020). Whilst concerns on the growing issue of plastic pollution have long been around (e.g. see Law, 2017), *Blue Planet* has been found to have had a notable impact on the wider public's perception of this serious and growing environmental issue (Males and Van Aelst, 2020; Dunn *et al*., 2020). This raised the question - could the existing gallery spaces be used in a way that engaged the public further, potentially evoking positive behaviours in response?

Studies evaluating the psychological effects on people's behaviour in response to such environmental concerns have been made utilising psychological distancing concepts such as Construal Level Theory (Trope and Leiberman, 2010). Such methods consider the way in which our mental representations depend on their closeness to our present situation. This theory posits that a psychologically distant object will be construed in an abstract manner (high construal level), whereas a psychologically closer object will be construed in a more concrete manner (low construal level). Construal levels will thus expand and contract depending on a person's mental horizon.

Such principles have been applied to developing a better understanding of psychological distancing in order to promote pro-environmental behaviours especially in relation to major issues such as climate change (e.g., Griffioen *et al*., 2016). With more definable environmental issues such as plastic pollution, it has been demonstrated how distinct emotional responses to images on plastic pollution can lead to a differential influence on a person's decision making in reducing their plastic consumption, depending on the response initiated such as "disgust" or "sadness" and the message that is linked to it such as "why" or "how" (Septianto and Lee, 2020).

Overall, such studies conclude that people usually perceive higher risks when psychological distance is small, but that the effect of psychological distance on actual intentions and behaviour is much less clear cut. Whilst such psychological evaluations were beyond the scope and resources of this engagement project, the broader principles from such studies influenced the concept of utilising the Museum's gallery spaces as being a potential means of connecting people to the challenges faced from plastic pollution in the marine environment. By using these spaces in an unexpected way, we have an opportunity to re-engage visitors with previously static or unchanging spaces that potentially enables a reduction of the construal levels that brings individuals closer to the issue and allows them to feel more enabled to enact pro-environmental behaviours (e.g., see Wang *et al*., 2019). Unfortunately evaluating projects such as this for effects such as changes in construal theory levels is usually out of the scope and available resources but would warrant attention in future projects of this type so that we can better understand the true impact of such initiatives.

Reimaging the Gallery Spaces

Amgueddfa Cymru is a large interdisciplinary museum covering a wide diversity of collections areas across seven museum sites and a dedicated collections centre. The National Museum Cardiff site is the primary focus of the Art and Natural Science collections, housing both significant permanent and temporary gallery spaces and collection stores. Within the natural science dedicated galleries are a number of large, open diorama style displays, many of which are themed around the marine environment (Figure 1). These have remained largely unchanged since their creation in the mid-1990s but continue to remain very popular with visitors and staff alike. On occasions these permanent displays are also used in innovative ways to support various museum events and activities, a prime example being the 'Museum of the Unexpected' event (Doyle, 2016) in support of the children's author Ronald Dahl's anniversary where the dioramas were used in quirky, fun, and unexpected ways to support the event (Figure 2).

Such activities formed the basis of the concept of using these diorama display spaces in a more serious way to highlight challenging issues such as plastic pollution. Discussions with colleagues in the Museum's learning team raised the possibility that utilising these spaces to highlight plastic pollution as a museum activism project could be a pilot idea that the Museum's Youth Forum would potentially like to take on board and develop further. The Youth Forum group is an inclusive social space for young people aged 14-26 that meets regularly to engage with museum projects and are encouraged

Figure 1. An example of the marine themed displays used in the intervention. Seashore and sea cliff Diorama (left); the leatherback turtle display (right) © Amgueddfa Cymru

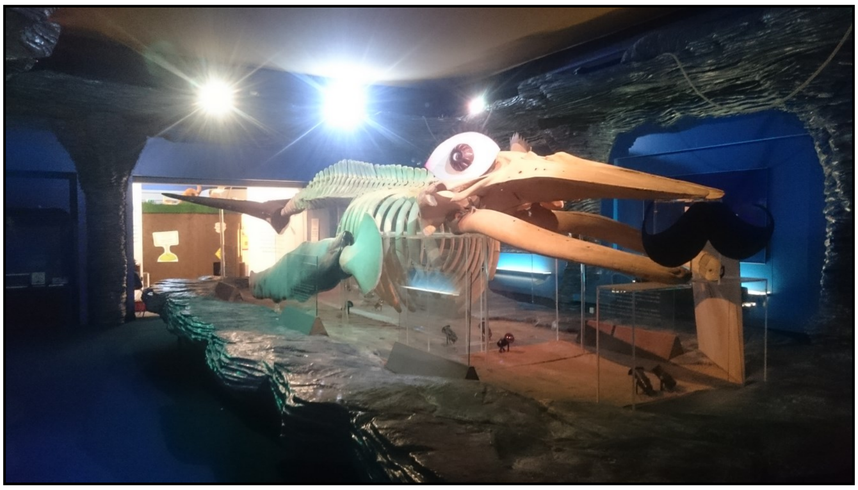


Figure 2: 'Whale with googly eyes and moustache' – dressing up the humpbacked whale skeleton for a 'Museum of the Unexpected' event. © Amgueddfa Cymru

to be partners in decision making and organising activities. The idea was thus presented to the group who responded with great enthusiasm to the concept (Younan and Jenkins, 2020), and from this the idea was embarked upon as a youth led museum activism project.

Museum Conservation Supporting Youth Activism

The Youth Forum wanted to keep with the concept of museums focusing on showing authentic objects and specimens and were keen to use real beach-collected plastic waste to highlight its significant impact on the environment. From the onset of the project the Youth Forum team worked closely with the Natural Science Conservator and other specialist museum staff to explore what the issues would be with the plastic waste and how they could be mitigated so that the beach waste would be safe to handle, enabling it to be used safely in the displays within the Museum's natural science exhibition spaces. Bringing untreated beach waste directly into the museum environment would pose a range of significant issues, particularly around risks to collection care and general health and safety. To enable this idea then a number of challenges had to considered, such as:

- Storage of the material.
- De-contamination of the plastic waste.
- Removal of hazardous substances and items, such as fishing hooks and syringes from the plastic waste.
- Using waste plastic of different sizes, textures and thickness in the workshops.
- Devising ways of installing plastic in the maritime exhibits that would convey a message to visitors without damaging the displays or present risks to people.

Going through these issues enable protocols to be established that made the use of such plastic waste material feasible within the exhibition spaces. The Youth Forum then reached out to other community groups, particularly 'Surfers Against Sewage' who subsequently worked closely with the Youth Forum to organise plastic waste collections from beach clean ups and shared their hands-on experiences of dealing with the problem of plastic pollution.

The collected plastic waste was then passed through a series of protocols established with the Youth Forum when it arrived at the Museum. This began with the isolation and freeze sterilisation treatment of the material to kill any insect pests using one of the natural science departments dedicated walk-in freezer units. After three weeks in the freezer the material was removed, washed with clean water and detergent, and then dried. The waste was then actively sorted through to remove all the hazardous waste and unpleasant items such as used needles and condoms (Figure 3). All this work was carried out by the Youth Forum with supervision from museum staff.

The cleaning and sorting were a challenging task for youth forum members and the team quickly realised they would need to involve others to be able to move on to the next stages of the project. Additional help was sought from other volunteers and museum assistants which also provided an opportunity to share the project with others across the museum. Going through this process also gave the team involved a practical and positive insight into why museums have to handle collections and materials in the way that we do, preventing insect pests getting into the collections and ensuring no toxic or hazardous materials will affect the collections, displays, or people. Working

Figure 3. Cleaning and sorting the plastic waste. © Amgueddfa Cymru

through the waste in this way also had a significant impact on the young activists especially around the amount of waste they were handling and the different types of materials in it, such as the excess of small plastic toys or used light sticks.

After the waste had been appropriately treated, cleaned, and sorted the next part of the project was to start devising ways of using this material safely within the exhibition displays that would create the impact the young activists were after using a mix of creativity to make interventions for the exhibition displays from the rubbish, but also to use the rubbish as what it effectively was i.e. as rubbish. The timescale of the project, the large amount of plastic and size of the marine themed displays quickly led the youth forum to realise that they needed further help again in preparing their installations for the galleries from the plastic waste. This provided an opportunity to get further young people and the wider public involved in the project through a series of workshops which included:

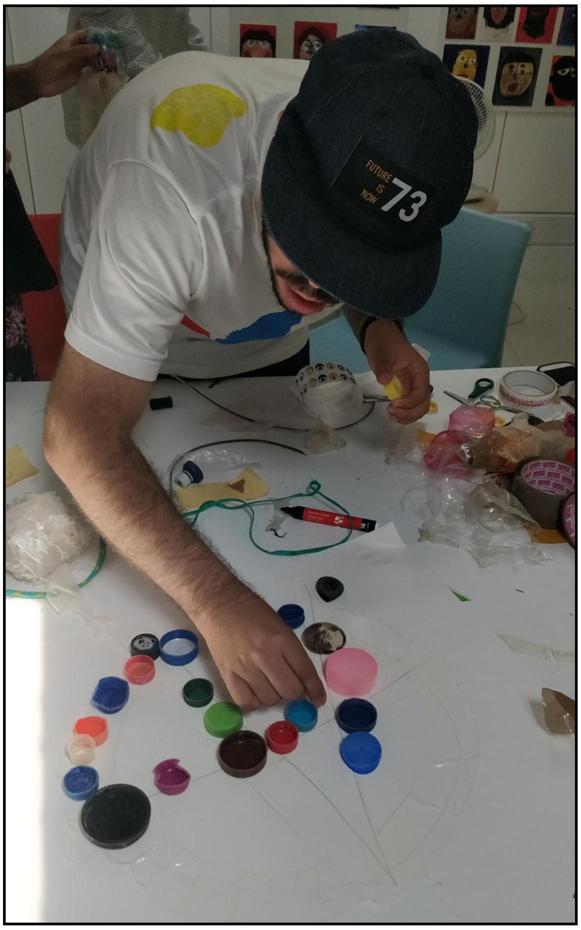


Figure 4. Working with the cleaned and sorted plastic waste to create various creative pieces for use in the intervention. © Amgueddfa Cymru

- Drop-in workshops for children and parents at the Waterfront Museum in Swansea.
- Targeted workshops with community partners at the National Museum Cardiff.
- Independent off-site workshops by external youth groups, including beach cleans and creative workshops.
- Special needs workshop with Cathays Community Centre Inclusive Youth Provision.
- Individual contributions e.g., stop motion animation by a youth forum member with autism and illustrations by young trans illustration student.

These collaborations had further impact on the young activists as the project progressed as they realised that this material was genuinely going to be used within the Museum's exhibition spaces, and that they were the main drivers and creators of the project giving them a strong sense of ownership and trust with the intervention project (Figure 4).

Finalising the Interventions Design

The project was very much a collaborative effort and roles within the Youth Forum were shared depending on the abilities and talents of those involved. Youth forum members shared what they had produced with each other at their regular meetings and via regular visits to the marine displays to help their ideas take shape and evolve. During these gallery visits they discussed with museum staff the practicalities of installing the intervention, chose spaces for banners and displays, discussed health and safety and risk assessments, and formed a vision of what they wanted their gallery intervention to look like. Such sessions were important because it helped to form a realistic vision of how they were going to do the intervention and how that message would get across to our visitors.

From this a firm plan was drawn up by the Youth Forum, in close collaboration with the Natural Science Conservator and other museum staff, about how the gallery spaces were going to be utilised, and the way all the creative sea creatures and various interventions were going to be pulled together in the various gallery spaces (Figures 5 and 6). In addition, the Youth Forum working closely with their youth engagement coordinator from the Learning department developed their own text and created new videos to be incorporated into the intervention. This enabled them to exhibit further skills and creative talent such as re-imagining aspects of the plastic waste such as the flip flop as some sort of marine creature, with its life history (see figure 6).

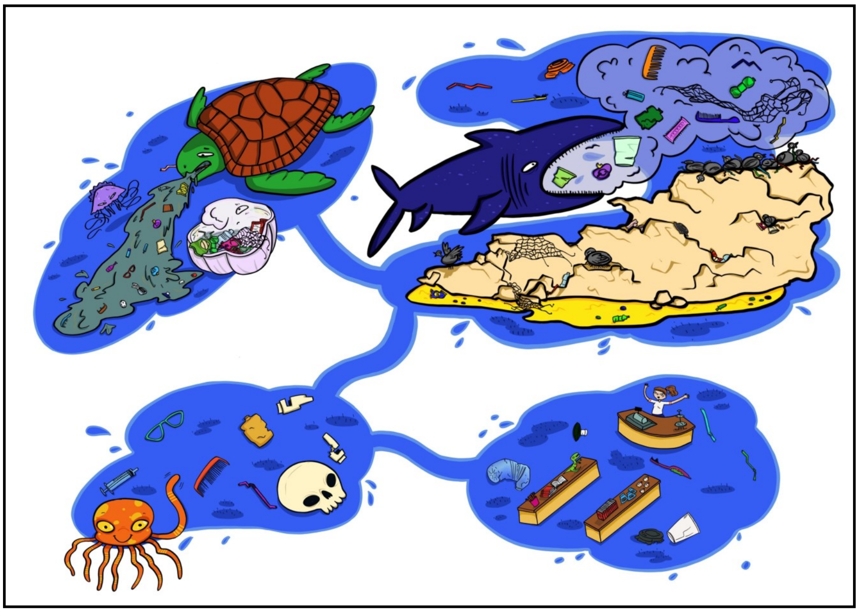
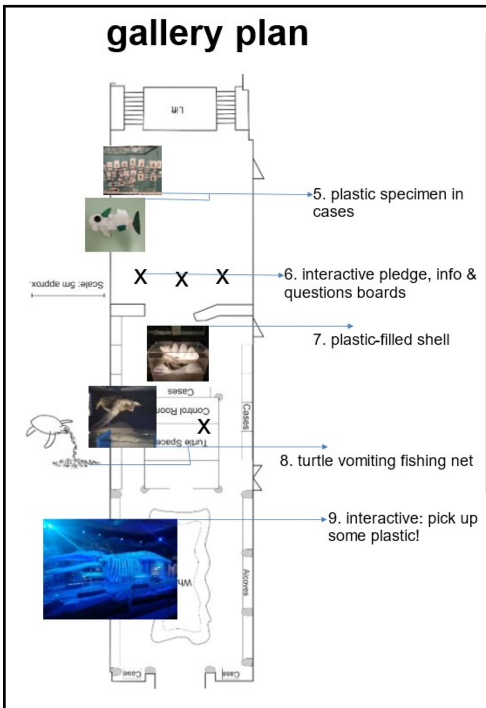


Figure 5. An illustration drawn up by one of the young activists envisioning how all the various activisms in this Gallery spaces would be linked together. © Amgueddfa Cymru

Installation

With the mass of rubbish cleaned, treated, turned into numerous creative plastic works, and the design finalised, then the next step was installing the work. Once again, the young activists were very much involved in this process, working closely with specialist staff such as the Natural Science Conservator in enabling the install and arranging the various creations, bringing themed displays together around the dioramas, and scattering the conserved rubbish throughout many of the permanent displays and dioramas (Figure 7). The Youth Forum were supported by the appropriate staff with H&S tasks who used the lift platforms to hang objects from the ceiling and opened display cases to allow the addition of the rubbish and other creations. Being an active part of the installation process gave the participants both experience and an understanding of the technical side of museum gallery work and the way exhibitions are put together, along with the health and safety issues that need to be considered to ensure we created an impactful but safe intervention for all involved (Figure 8).

The installation process also surprised the young activists around the freedom they were given with the galleries for the intervention. Although the Youth Forum were supervised, this was kept to a minimal level to ensure their activities within the



Example of Display text by youth forum members:

Abiicias Lopitus (commonly known as discarded flip-flop) - Always paired for life, careless action sees many flip-flops cruelly separated from their mate. Lost flip flops wander the ocean for tens, if not hundreds of years seeking their lost mate. The misery of its lonely existence is matched only by their destructive plastic footprint.

Figure 6. Part of the finalised gallery plan with an example of associated display text developed by the youth forum in close collaboration with specialist museum staff such as the Natural Science Conservator. © Amgueddfa Cymru

Figure 7. The young activists took an active part in the gallery install of the intervention, and utilised social media throughout the project to promote their work. © Amgueddfa Cymru

spaces were safe to both themselves and the collections but provided enough freedom for them to make decisions on the various installations. This unprecedented access and trust they were given to intervene and alter the displays had a really positive impact on their own connection with the project and what they were able to achieve, and this was strongly reflected in the comments received for the post intervention evaluation report (Mannay, 2019).

Additional supporting materials were also prepared by the Youth Forum working in close liaison with the Learning team. This included replacing some of the exhibition display videos with animations of their own, and producing pop up banners and display boards introducing the gallery intervention with an explanation of what they had done here working with the actual beach collected plastic, along with the way it had been treated, cleaned, and made safe by working in close liaison with the specialist Natural Science conservator and other colleagues who were supporting them. This brought another window into the behind-the-scenes work of museums that is essential in supporting such outreach activities but often not highlighted. In addition, various social media feeds and blogs were developed to promote and share the intervention project linked by the hashtag #NoMôrPlastic.

Figure 8. An example of the materials prepared to introduce what the young activists were doing and why they were doing it that could be shared on social media feeds, on the Museum's website, and as an introduction to the space when the intervention was running. © Amgueddfa Cymru

Opening the Gallery Intervention

At the end of July 2018, coinciding with the start of the busy summer holiday period, the intervention was opened. There was no prior advertising, and most staff were completely unaware of the intervention, and this included the front-of-house museum assistants. The intervention remained in place for a single week and was then completely removed from the gallery spaces as if it had never been there. This had been an intentional approach from the start to create an 'unexpected' experience to the gallery intervention by not preparing visitors for the changes that had been instigated. Feedback received from both staff and visitors supported this approach to have given the gallery intervention and its message greater impact (e.g. see Younan and Jenkins, 2020).

The gallery intervention started in the front downstairs natural science gallery spaces of the National Museum Cardiff amongst the large open diorama displays of the seashore and seacliff (see Figure 9), before moving into the marine themed displays on the following mezzanine level (examples in Figure 10). This part of the exhibition space includes two iconic specimens, a leatherback turtle and humpback whale skeleton which were incorporated into the gallery intervention (Figures 11 and 12). Many of creations constructed in the intervention were later used in other events and activities.

During the week of the gallery intervention, the young activists ran a series of linked workshops and interactive sessions within the gallery spaces to facilitate engagement with the public. This included various activities and pledge boards which both furthered engagement with visitors and developed the communication skills of the young activists. From a collections care perspective, the open use of marker pens and stickers in the gallery environment did raise concerns but fortunately there were only a few minor instances of stray stickers on displays and offensive phrases on the pledge boards which suggested a high respect for both the intervention and the museum. As it was the summer school holiday period the gallery intervention attracted many families with young children who noticeably engaged with the difficult topic of plastic pollution with each other, and a fuller discourse on the feedback and impacts of the project are discussed in Mannay (2019) and Younan and Jenkins (2020).

The closure and removal of the intervention after only a week surprised many who felt it should have run longer (Mannay, 2019) but was a deliberate choice to give the process a sense of impact and

Figure 9. (a) Looking into the main gallery space with the basking shark and seashore diorama. (b) A close up of the intervention around the cormorant display. © Amgueddfa Cymru

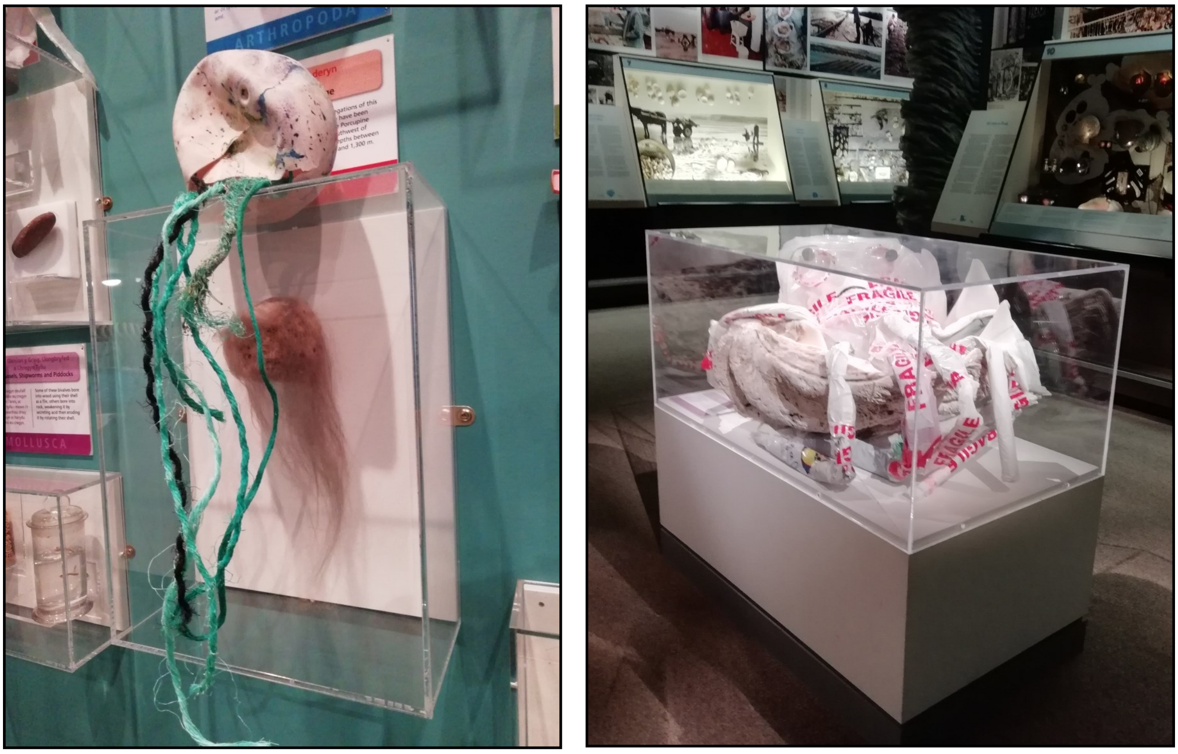


Figure 10 Examples of the creative additions that were placed, along with assorted items of plastic rubbish, into and around the existing displays. © Amgueddfa Cymru

Figure 11. The intervention highlighted the serious threats to species such as leatherback turtles from plastic pollution and ghost fishing gear. © Amgueddfa Cymru

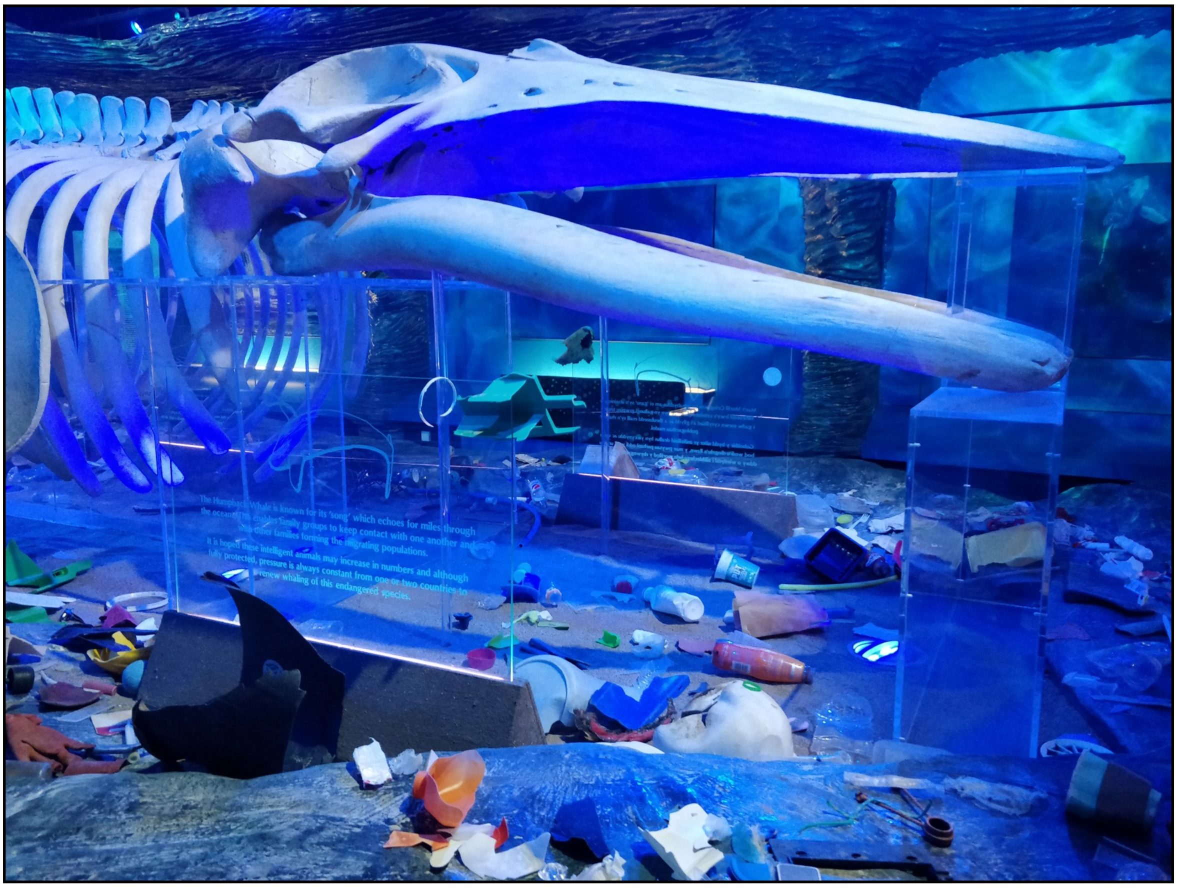


Figure 12. The humpback whale skeleton display received a very liberal coating of the prepared plastic waste. However, this was also added to by visitors during the intervention period. © Amgueddfa Cymru

change in the Museum spaces involved. It was also notable when clearing the intervention from the gallery displays that areas with the plastic rubbish such as around the humpback whale skeleton (Figure 12) had accumulated further rubbish during the intervention from some visitors themselves. This provided an insight into the psychology of some of our visitors in that, for some people at least, rubbish attracts further rubbish (Cialdini *et al*., 1990). Such rubbish was removed and recycled or disposed of, and the museum has active monitoring in place for potential insect pest issues that may have risen from the untreated rubbish.

Legacy and Sustainability

From the intervention's start, an evaluation was run in collaboration with Cardiff University which is available as part of the wider detailed report on the 'Hands on Heritage' project in Mannay (2019). This research highlighted that the intervention had a significant impact on both visitors and staff alike, particularly from the creative and unexpected way that the project was carried out creating a feeling of surprise that supported active engagement with the intervention and its message. It was also noted that often the younger family members led their parents into the discussions initiated. The intervention also highlighted how permanent museum displays can be re-envisaged in creative ways that have an impact through the initiated change from what was previously normal.

The work put into this project was also further utilised in a variety of other activities and events. This included some elements being incorporated into a significant exhibition called 'Coast' at one of Amgueddfa Cymru's partnership gallery spaces at Oriel y Parc, St Davids, Pembrokeshire. The exhibition incorporated artworks and natural science items to reflect the coastal environment around Pembrokeshire and included some notable artworks including a piece called 'Calm' by the Dutch master, Jan van de Capple (1626-1679). In amongst the artwork was disperse various birds and marine species from the natural science collections and incorporated amongst the whole exhibition were aspects of the plastics intervention (Figure 13). The display ran for six months and had a significant impact with visitors and school groups

Figure 13. Examples of the plastics intervention being incorporated into the multidisciplinary 2018 exhibition 'Coast' at Oriel y Parc, St Davids. © Amgueddfa Cymru

to the exhibition and received many repeat visits (Oriel y Parc, 2018).

Moving forward, the youth forum also expressed their wish to develop this project into a repeatable format for future youth-led interventions which they want to use for 'activism' to discuss and highlight different social and environmental topics. They were vocal in their own evaluation of this project, actively discussing the strengths of what was achieved along with the areas that need improvement. From this they formulated further ideas for structures and processes which can enable this method of youth-led museum interventions to be taken forward and developed into a formalised museum process via a series of workshops with both staff and community partners, drawing on their expertise on children's and young people's rights and experience in developing democratic youth-led structures (Mannay, 2019).

Summary

The overall impact of this and the other 'Hands on Heritage' associated projects on the young people involved has been extensively reported upon by Manny (2019) and Youan and Jenkins (2020). This review has been focused more at providing an overview of the project and how the knowledge and skills of specialist collection care staff supported the enabling of such an innovative project. This highlights the importance and value of often overlooked behind the scenes specialisms that are fundamental to supporting such outreach activities. The 'No Môr Plastic' project was also noteworthy because it actively facilitated utilising display space both within and beyond Amgueddfa Cymru, enabling a wider public viewing of the artefacts created and curated by the young activists. The significance of this was recognised by the Youth Forum members involved and the intervention positively demonstrated how youth-led environmental projects can be a dynamic part of the museum environment.

Supporting activities such as this intervention also provided a useful means to allow the re-evaluation of the way we work and how we can be more receptive to communities and the bigger challenges facing our society and the world around us. The young activists were very involved with this project and were notably surprised by how much freedom they were given and how much their creative process was taken on board and utilised. They also appreciated the practical issues around planning, health and safety, and the importance of looking after the collections and display spaces themselves. Overall, it brought the way we work together and actively demonstrated how normally static museum displays can be enhanced to created new impacts (Mannay, 2019, Younan and Jenkins, 2020). Younan and Jenkins (2020) themselves concluded that "*audiences do want to engage with challenging themes in the museum environment, and that concerns around upsetting content should be weighed up against the positive impact that an activist museum environment can have*".

The project also represented a different way of working for an institutional environment such as Amgueddfa Cymru where all activities need to be discussed with, and sanctioned, by members of staff. The youth forum still had to depend on 'gate keepers' (curators, conservators, and other members of staff) to successfully implement the gallery interventions and whilst there were some frustrations between the Youth Forum and navigating institutional processes such issues were resolved by the staff involved supporting the young activists as fully as possible in order to try and ensure they were the core driver and creators of the project.

For the specialist collections staff involved in the project such as the Natural Science Conservator this was a great opportunity to use skills and knowledge to enable using the beach plastic waste in the museum environment demonstrating that challenging materials can be utilised safely in the gallery environment. This reflects on a wider attempt by the museum sector to tackle objects and materials that would have previously been seen as too challenging in order to reflect the effects of human activity on the environment and other social concerns (e.g. see Þórsson, 2018). For other staff such as the Museum Assistants the unexpected nature of the gallery intervention, and the way it engaged visitors, provided diversity and change in the exhibition spaces enhancing their own engagement within their regular workspaces. Other staff were also positively taken by the changes, with one of the directorate reflecting '*I've walked past the dioramas and the turtle for twenty years and have inevitably got used to seeing them the way they've always been. Your work was a real wake-up call and so good to see the museum responding rapidly and boldly to such an important topic.*'

Overall, this was found to be a highly positive and engaging project for all involved, providing an opportunity to highlight a critical environmental issue in an innovative way but also to bring young people and their skills into the forefront of museum based activism.

Acknowledgments

My thanks go to my learning colleague Sarah Younan, who was the Youth Forums main youth engagement coordinator on the project, for sharing the feedback and experiences of the young activists that made the writing of this overview possible. I would also like to thank the two anon referees for their constructive feedback in finalising this paper.

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NatSCA AGM 2022

6.00pm BST, 7th June 2022

Hybrid meeting:
SPNHC Edinburgh, Lecture 2, Appleton Tower & Zoom
ZOOM link emailed to members

AGENDA

1. Apologies for absence
2. Matters arising from Minutes of AGM Thursday 27th May 2021, held on Zoom as published in *Journal of Natural Science Collections* **10**: 146-154 (2022)
3. Reports
4. Election of NatSCA committee
5. Any other Business
6. Vote of thanks
7. Next AGM venue

Close

AGM

1. Apologies for absence
Patricia Francis, Holly Morgenroth, Amy Geraghty

2. Matters arising from Minutes of AGM Thursday 27th May 2021, held on Zoom as published in *Journal of Natural Science Collections* 10: 146-154 (2022)

Proposal to accept the minutes of the 2021 AGM, including any amends from matters arising, as an accurate record:

Proposer: Paolo Viscardi
Seconder: Glenn Roadley

Please ensure you are a paid-up individual member of NatSCA to propose, second or vote at our AGM. Institutional members are non-voting members. If you are attending via ZOOM and would like to propose or second, please write your full name in the conference 'chat' channel. Many thanks.

3. **Reports:**

Secretary's Report: Yvette Harvey

Eight Zoom committee meetings have been held between February 2021 and January 2022. 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 and green denotes a non-Trustee period):

	ii.2021	iv.2021	v.2021	vii.2021	Viii.2021	x.2021	xi.2021	i.2022
Jack Ashby	y	y	y	y	y	y	y	
Clare Brown	y	y	y	y		y	y	
Amanda Callaghan			y					
Jan Freedman								y
Jennifer Gallichan	y	y	y	y	y	y	y	y
David Gelsthorpe	y	y		y	y	y		y
Isla Gladstone	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		
Laura McCoy				y	y	y	y	y
Holly Morgenroth	y	y	y	y	y		y	
Bethany Palumbo	y		y			y		
Glenn Roadley	y	y	y	y		y	y	y
Laura Soul				y	y	y	y	y
Paolo Viscardi	y		y	y	y	y		y
Donna Young	_	_	y	_	_	_	_	_

Treasurer's Report: Holly Morgenroth

Accounts summary 01.02.2021 - 31.01.2022

Income	2021-22		2020-21
Institutional Subscriptions			
Previous Years	200		80
Current Year (bank)	1,938		2,624
Current Year (PP)			
Future Years	-		40
		2,138	2,744
Personal Subscriptions			
Previous Years	20		64
Current Year	5,455		5,087
Current Year (PP)			
Wrong amount	30		
Future Years	-		113
		5,505	5,265
Workshop Income			
Entomology	-		75
Basics 2020			1,279
		-	1,354
Conference Income			
2020			780
2021	240		
		240	780
Donations			
Donations	44		
		44	19
Other			
Misc.	0		
Bank interest			17
Unallocated	0		
		0	17
TOTAL INCOME		7,927	10,179

Expenditure	2021-22		2020-21
Running costs			
Committee Expenses	- 95		- 537
Website, Zoom	- 1,187		- 867
Stationery			- 73
Postage	- 22		
Data Protection	- 35		- 35
		- 1,339	1,512
Workshops			
Basics 2020			- 437
		-	- 437
Conference			
2019			- 200
2021	-		
		-	- 200
Publications & Information Provision			
2020 Journal print & postage	- 1,592		
2019 Journal print & postage			- 1,748
		- 1,592	- 1,748
Charitable			
Bill Pettit Fund	- 4,510		- 1,840
Bursaries		-	
Sector support		-	
		- 4,510	- 1,840
Other			
TOTAL EXPENDITURE		- 7,441	- 5,737
Excess Income over Expenditure		486	

OUTSTANDING EXPENDITURE	
BP - Beetles Aberdeen 2021	£ 1,165
BP - Last passenger SS Great Britain 2020	£ 1,362
BP - Teeth - KCL 2020	£ 2,100
Journal	£ 1,600
December meeting	£ 123
	£ 6,350
EXPECTED INCOME	
	£ -
Adjusted balance estimate 31.01.2022	£ 42,441

Cash Flow Statement			
01.02.2021	Current a/c	£ 21,259	
	Deposit a/c	£ 22,475	
	Paypal a/c		
			£ 43,734
31.01.2022	Current a/c	£ 48,791	
	Paypal a/c		
			£ 48,791
NB Adjusted balance			£ 42,441
			-£ 1,294

Charity Commission report for signing after AGM approval

CHARITY COMMISSION FOR ENGLAND AND WALES	Natural Sciences Collections Association		1186918		CC16a
	Receipts and payments accounts				
	For the period from	Period start date 01.02.2021	To	Period end date 31.01.2022	
Section A Receipts and payments					
	Unrestricted funds to the nearest £	**Restricted funds** to the nearest £	**Endowment funds** to the nearest £	**Total funds** to the nearest £	**Last year** to the nearest £
A1 Receipts					
Institutional subscriptions	2,138	-	-	2,138	2,744
Personal subscriptions	5,505	-	-	5,505	5,265
Workshops		-	-	-	1,354
Conferences	240	-	-	240	780
Bank Interest		-	-	-	17
Misc		-	-	-	-
Donations	44	-	-	44	19
		-	-	-	-
Sub total*(Gross income for AR)*	7,927	-	-	7,927	10,179
A2 Asset and investment sales, (see table).					
	-	-	-	-	
	-	-	-	-	-
Sub total	-	-	-	-	-
Total receipts	7,927	-	-	7,927	10,179
A3 Payments					
Running costs	1,339	-	-	1,339	1,512
Workshops		-	-	-	437
Conferences		-	-	-	200
Publications & Information provision	1,592	-	-	1,592	1,748
Bill Pettit Memorial Fund		4,510	-	4,510	1,840
Bursaries		-	-	-	-
Sector support		-	-	-	-
Sub total	2,931	4,510	-	7,441	5,737
A4 Asset and investment purchases, (see table)					
	-	-	-	-	
	-	-	-	-	
Sub total	-	-	-	-	
Total payments	2,931	4,510	-	7,441	5,737
Net of receipts/(payments)	4,996	- 4,510	-	486	4,442
A5 Transfers between funds			-	-	-
A6 Cash funds last year end	38,734	5,000	-	43,734	41,113
Cash funds this year end	43,730	490	-	44,220	45,555

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

Categories	Details	Unrestricted funds to nearest £	Restricted funds to nearest £	Endowment funds to nearest £
B1 Cash funds		43,730	490	-
			-	-
		-	-	-
	Total cash funds	43,730	490	-
	(agree balances with receipts and payments account(s))	OK	OK	OK
	Details	Unrestricted funds to nearest £	Restricted funds to nearest £	Endowment funds 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 2021	unrestricted	1,165	
	Bill Pettit 2020	restricted	3,462	
	Committee Expenses	unrestricted	123	
	Journal 2021	unrestricted	2,000	
			-	
Signed by one or two trustees on behalf of all the trustees	Signature	Print Name		Date of approval

Signed by one or two trustees on behalf of all the trustees:

Isla Gladstone (7th June 2022)

Yvette Harvey (7th June 2022)

Accounts will be signed when agreed at AGM.

Proposer: Karen Manton
Seconder: Laura McCoy

Membership Secretary's Report: Clare Brown

For 2021 the membership statistics are as follows:

> 334 members (59 institutional, 274 personal), this is 28 fewer members than 2019-20.
> Around 80% of our membership is UK based, we also have members in 20 other countries.
> 153 members chose 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).

The slight drop in membership numbers is probably due to the spike last year's Decolonisation conference attracted. This online conference in 2020 allowed members free access and we had nearly 70 new members join us in the two months running up to the conference on 19th November.

The number of people taking a hardcopy of the journal has dropped again, down 17 copies on last year.

I would like to thank everyone who has supported me with the membership work over the last year, Holly Morgenroth, Glenn Roadley and Justine Aw in particular.

Editor's Report: Jan Freedman

This year we have produced two Volumes of the Journal of Natural Science Collections. Volume 9 was published in November 2021. This special Volume focuses on papers from the 2020 Decolonising conference and papers include allyship in museums, decolonising mineral collections, examining the colonial history of a Victorian game hunter, and decolonising the way we talk about Australian mammals. This special Volume is open access, and has been published online only (www.natsca.org/jonsc-vol-9). There is no hard copy option available for this Volume.

Volume 10 of the Journal of Natural Science Collections has been published and is available both online and in print. Members who requested a hard copy of the Journal will have received it by now, and a password was given to all members to access the online articles. Volume 10 was published a little later than planned due to several key people contracting Covid. Thankfully the individuals are better and back to their good health. Volume 10 includes articles about collections research, conservation, and using collections through display and events.

I would like to thank the Editorial Board for their assistance in finding expert peer reviewers for the articles; Bethany Palumbo, Paolo Viscardi and Rob Huxley. I would like to give a special thanks to all the reviewers who have spent so much time on going through each article and providing constructive feedback to improve the quality of them for publication. I am extremely thankful for their time, especially during the last year with the Covid pandemic.

I have received two submissions for Volume 11 which is due to be published in January 2023. If you are interested in submitting an article for the Journal, or have an idea about an article you would like to write, please contact the Editor (Editor@natsca.org).

Chair's Report: Isla Gladstone
1st February 2021 – 31st January 2022

NatSCA has continued to adapt over the past year to virtual working and ongoing sector challenges resulting from the Covid-19 pandemic. The trustees have been meeting monthly over Zoom, and continuing to explore new ways of working and how we can best support our members and wider community.

Our two trustees who joined at the 2021 AGM, Laura Soul and Laura McCoy, have developed a new trial offer called 'Lunchtime Chats' – aimed at increasing regular engagement with members and taking advantage of new online capabilities. The Chats are intended to be an informal gathering on Zoom, where members can talk about something of professional interest – perhaps an exciting development at work, a project they would appreciate community advice on, or a technique they'd like to demonstrate. The idea is to provide a friendly and informal slot, outside of a formal conference or training workshop. The talks are on the last Thursday of every month, aiming to range from around 10 to 30 minutes in length with time for questions at the end. In addition to the talks, the training group is looking to past events and surveys to develop ideas for a return to seminars and practical workshops in 2022/23.

In May 2021, we delivered our second virtual conference – this time on 'Changing the World: Environmental Breakdown and Natural Science Collections'. The presentations from this conference are now available online on NatSCA's website.

Our conference group, led by Glenn Roadley, has also been preparing for the 2022 conference. We are partnering with the Society for the Preservation of Natural History Collections (SPNHC) and Biodiversity Heritage Library for a hybrid in person and digital conference in Edinburgh in June. Recognising the international opportunities this brings, but also the significant cost of a larger conference for attendees, we are delivering a significant bursary offer of five bursaries of up to £250 each towards in person attendance and ten bursaries of £115 each to cover virtual attendance [Update: 10 in person and 2 digital bursary applications were approved in March 2022, as though the distribution differs from the original number of bursaries offered, the total value falls within the original budget]. We have also condensed our key delivery at this conference into one day, to enable members to attend at a one day rate. This includes our AGM and two symposia: 'Long time no see – updates from the natural science community' and 'Civically engaged museums – transforming public programmes to stay relevant'.

Our financial support activity also continues through the Bill Pettit Memorial Award. Three projects were awarded £5675 in 2021: Conservation of a Bateman ichthyosaur specimen at Sheffield Museums Trust, River Otter Beaver Taxidermy at the Royal Albert Memorial Museum Exeter, and re-imagining Marvellous Molluscs at the University of Aberdeen. After inevitable delays due to the Covid-19 pandemic, these have now been completed. They have been written up for the NatSCA blog, where you can get a taste of the benefits they have achieved. Our thanks to David Gelsthorpe for administering these grants, and everyone we have worked with on them. The Bill Pettit award is currently paused whilst we recruit new trustees and volunteers to support its running.

NatSCA continues to support collections at risk, for example through letters of support to senior stakeholders. However, our priority in advocating for natural science collections remains supporting understanding of their scientific and societal relevance - through our platforms, resources and partnerships.

This year we have been partners in an important AHRC-funded 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 will provide an overview of UK collections and digital capabilities. We will also be supporting future phases, to secure longer-term funding and infrastructure.

NatSCA is currently 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.

In spring to autumn 2021, NatSCA was also a partner in a seed funded NERC/AHRC project called 'Environment and Empire in the Museum', represented by trustees Jack Ashby and David Gelsthorpe. This consisted of a network, video series and workshop bringing together natural scientists, historians and curators working with natural history collections, to help consider particular challenges faced in exploring the hidden histories of environmental science.

We have also continued to represent natural science collections through mechanisms such as the steering group of the Subject Specialist Network Consortium, where Paolo Viscardi is our representative.

NatSCA's blog has continued to gain readers, with the number of visits and views to our pages both higher compared to previous years. Blog editor Jen Gallichan reports that 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. 2021 saw the most striking increase in engagement from our colleagues in India, as well as increased numbers of views from colleagues in Australia, Ireland and Canada. The most viewed posts in 2021 focused on collections and conservation projects. These included 'Private bone collections: the good, the bad and the illegal', 'Giant Sequoia at the Natural History Museum' and 'Telling the truth about who really collected the "hero collections"'. A total of 48 articles were posted.

NatSCA's website has had fairly consistent traffic across the period according to trustee Glenn Roadley, with a few spikes in traffic around April, May and September. Overall figures for the year are up compared to 2020-2021. Website updates have included new journal articles and 67 sector job vacancies. Following the 2021 NatSCA conference, a new 'Natural Science Collections and Environmental Action' hub was added under the 'Resources' section. Several broken links to external resources have been repaired after being flagged by members.

4. **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 **Membership Secretary**:

Nominee	Position	Proposed	Seconded
Clare Brown	Membership Secretary	Milo Phillips	Rebecca Machin

There is one vacancy for Membership Secretary and one nominee.

Below is the nominated candidate for **Editor**:

Nominee	Position	Proposed	Seconded
Jan Freedman	Editor	David Waterhouse	Yvette Harvey

There is one vacancy for Editor and one nominee.

Below is the nominated candidate for Treasurer:

Nominee	Position	Proposed	Seconded
	Treasurer		

There is one vacancy for Treasurer and no nominees. As we have not received nominations for this position, NatSCA will seek to appoint a Treasurer who has financial skills and experience following the AGM, to be ratified at the 2023 AGM.

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

Nominee	Position	Proposed	Seconded
Jennifer Gallichan	Ordinary Member	Harriet Wood	Yvette Harvey
Tannis Davidson	Ordinary Member	Jack Ashby	Natalie Jones
Amy Geraghty	Ordinary Member	Paolo Viscardi	Nigel Monaghan
Patti Wood Finkle	Ordinary Member	Yvette Harvey	Isla Gladstone

There are four vacancies for Ordinary Members and four nominees.

Proposal 1: we propose one 'en bloc' vote for all six nominees (one nominee for Membership Secretary, one nominee for Editor, and four nominees for ordinary member positions).

Proposer: Kate Andrews

Seconder: Jack Ashby

Membership vote: **Yes**

This will be a hybrid poll, with a greater than 50% vote required to accept the proposal. Please remember that only paid up individual members are able to vote at NatSCA's AGM.

Proposal 2: all six nominees (one nominee for Membership Secretary, one nominee for Editor, and four nominees for ordinary member positions) to be accepted as trustees.

Proposer: Laura McCoy

Seconder: Natalie Jones

Membership vote: **Yes**

This will be a live digital Zoom poll, with a greater than 50% vote required to accept the proposal. Please remember that only paid up individual members are able to vote at NatSCA's AGM.

5. Any other Business

6. Vote of thanks
NatSCA would like to thank everyone who has been involved in delivering our activities in 2021-22 for sharing their time, expertise and content.

We would like to thank the trustees named in the Chair's report for delivering key activity, as well as all trustees for contributing to the overall running of NatSCA. This includes behind the scenes roles: Treasurer Holly Morgenroth, Secretary Yvette Harvey, Membership Secretary Clare Brown, and Conservation lead Lucie Mascord. We also thank Justine Aw for highly valued external technical support. Jen Gallichan and the trustees would like to pass on heartfelt thanks to the great group of volunteers who compile our monthly Digital Digests including Glenn Roadley, Olivia Beavers, Milo Philipps, and Clare Dean. Our Editor Jan Freedman has shared thanks to the Editorial Board for their valued support: Bethany Palumbo, Paolo Viscardi and Rob Huxley.

NatSCA would like to extend special thanks to those trustees stepping down from committee this year. Donna Young will be retiring following a long period of special leave, having been part of the NatSCA committee since its merger of the Biological Curators Group and Natural Sciences Conservation Group. Donna has been instrumental in successful delivery of our conferences, as well as successful ongoing running of NatSCA. We would also like to recognise the fantastic contributions of our long-standing Treasurer Holly Morgenroth, who is stepping down this year. Both will be very much missed. Former Chair Paolo Viscardi and SPNHC representative Bethany Palumbo will also be stepping back as trustees, but will be retaining roles for NatSCA as co-opted Subject Specialist Network Rep and SPNHC Rep respectively. We look forward to working with both of them.

7. Next AGM venue - To be announced

Close
The meeting closed at 6.35pm

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