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Editorial

Rachel Jennings

Welcome to Volume 5 of the *Journal of Natural Science Collections*! It has been a busy year for the Journal team, which - excitingly - now includes an Editorial Board. The Board was established in June, following the 2017 NatSCA conference. The initial members have been vital in getting this Volume prepared, as they took the lead on managing the peer review process. I couldn't have done this without them, and I offer my grateful thanks for all their hard work.

I am also pleased to announce that members will be offered a paperless option for Volume 6 of the *Journal*, due for publication in January 2019, for those who would prefer electronic access. This helps to make NatSCA a more sustainable organisation, and will save money that can be spent in other areas to benefit our members.

This Volume is a particularly packed one – we received an overwhelming response to the call for papers, with a record 22 manuscripts submitted. 14 of these were accepted for publication, and are now in your hands!

I have arranged the articles broadly thematically: the first seven discuss various aspects of museum practice and research. **Ashby** argues that museums should not be afraid to be experimental; **Harvey, Swindells, and Simmons** describe a trial of a biscuit beetle pheromone at the Royal Horticultural Society (RHS), Wisley; **Freedman, van Dorp, and Brace** discuss the challenges and practicalities of destructive sampling in museum collections; **Duque-Thüs and Fulcher** discuss methods for re-curating plant tissue samples, and disaster-planning for these collections; **Miles** describes a project to re-curate and catalogue a collection of Venezuelan hawkmoths (which was funded by NatSCA through the Bill Pettitt Award); **Cane, Laventhol, and Ledger** describe a method for surveying UV reflectance in moths, using open-source tools; **Ziganira** discusses a project to georeference the Bivalvia collection at the KwaZulu-Natal Museum, using the online GeoLocate tool.

The next two papers are linked by the theme of expertise: **Roach and West** argue for the need to train future experts in taxonomy, and describe a traineeship programme run at the Angela Marmont Centre for UK Biodiversity; **Baker and Gill** describe the life, work, and collections of William Cash, one of the foremost early 'amateur' experts in palaeobiology and the fossils of the Coal Measures. Richard (Sandy) Baker sadly passed away while this paper was being prepared. I am very grateful to his co-author, Steve Gill, for completing the article, and glad to be able to publish it in Sandy's memory.

The last five papers all discuss collections on the move: **Allington-Jones** describes the conservation and transportation of a Mastodon skeleton to a new position in the Hintze Hall at the Natural History Museum (NHM), London; **Larkin** describes the conservation and re-mounting of an intriguing Asian elephant skeleton at the Cambridge University Museum of Zoology; **Garcia-Franquesa** describes the move of a whale skeleton at the Museu de Ciències Naturals de Barcelona, and its re-suspension in a diving posture; **Lowe** discusses the trials and tribulations of moving a museum collection on a tight schedule and budget, and offers advice; **Callaghan** describes the history of the Cole Museum of Zoology, Reading, as it prepares for a move to a new home in 2019.

I hope that you find this collection of articles interesting, inspiring, and useful. I would like to thank all of the authors for their hard work, and the many anonymous reviewers for generously volunteering their time and expertise.

View from the Chair

Paolo Viscardi

2017 has been a year of uncertainty, with the implications of Brexit still largely unknown, looming large over decision-makers and threatening to have a huge impact on staffing, funding, and legislation in the museum and natural sciences sectors. NatSCA has been trying to keep abreast of government consultation wherever possible, to flag issues affecting our members, such as with the recent consultation on the ivory trade. Clare Brown has also been talking with the Home Office to find a solution to the problems museums are facing with regard to expensive licenses for substances held in collections that are controlled by drugs legislation - at the moment, we're hopeful that the outcome will be Antiques Exemption certificates for museums with Accreditation. We've been updating documents on our website with information as legislation changes and will continue to do so, so watch this space [1].

We have also been engaging with the wider museums sector through the emerging network of Subject Specialist Networks (SSNs), with an email distribution group set up, a meeting supported by ACE early in 2017, and another meeting due in January 2018. This forum provides an opportunity for SSNs to share information and coordinate efforts to address issues such as collections at risk, which we continue to monitor and challenge within our limited power. Adding to our strength in this area, the Linnean Society of London offered to support and supplement our correspondence with the senior management of at-risk collections at the 2017 UK Taxonomy & Systematics Committee meeting, at which NatSCA represents UK-wide collections. As part of this role, I had the sobering task of presenting on *Biological Surveys and Museums: Past, Present, Future* at the Linnean plenary meeting in September [2]. As you might expect, the take-home message was mixed, with the role of museums varying significantly depending on their scale, focus, and history of involvement in recording and / or taxonomy.

At our annual conference, hosted wonderfully by the team at the University Museum of Zoology in Cambridge (a big shout-out to Natalie Jones, who coordinated), we explored the theme of *Evolving Ideas: provocative new ways of working with collections*. It proved a truly thought-provoking meeting, where the topics covered ranged from ethics to new approaches in analyses and object conservation. The unprecedented number of talks offered meant we had content for a substantial poster session, with many of the posters now available on our website [3], and the talks providing rich content for our blog [4] and publications, including this hefty volume of the Journal of Natural Science Collections. Managing such a deluge of contributions would not have been possible without the hard work of our new Editorial Board [5] and a small army of reviewers who have given their time to make this Journal what it is, but in particular I'd like to thank the Editor, Rachel Jennings, who has spent the year getting plans, processes, and guidance in place for the reviewers and Editorial Board (not to mention editing her socks off), and who is now working on getting Notes & Comments articles ready for publication.

We're currently gearing up for the next conference, which will be held in Leeds on 26th-27th April with the theme *The museum ecosystem: exploring how different subject specialisms can work closer together*. We would like to remind members that if they want to get involved with the NatSCA committee, the nominations are open for the elections to be held at the AGM in Leeds on Thursday 26th April [6]. At the 2017 AGM Lucie Mascord was voted onto the committee, replacing Vicky Purewal, who had stepped down. I'd like to thank Vicky for all the fantastic work she's done for NatSCA over the years. Lucie has taken on the role of Conservation Representative with gusto and has convened an initial Conservation Group meeting, and is in the process of planning a Conservation themed mini-conference for Autumn 2018. Our mini-conference for 2017 was *Bringing the dead to life: how to display museum natural science*, which proved to be an enlightening, enjoyable, and successful day thanks to our invited speakers, the room generously provided by UCL, and the organisational efforts of Clare Brown and Jen Gallichan.

We had a large number of excellent applications for the 2017 Bill Pettit Memorial Award, and after a difficult decision-making process we awarded funding to Manchester Museum for *Taking wing: Curation of a Venezuelan Hawkmoth collection* and Tullie House for *A Virtual Flora of Tullie: "Sowing the Seeds" to Digitise a Nationally Significant Herbarium*. However, we had a disappointingly low uptake of our individual bursaries for attending the conference, so I would like to encourage those of you who have to pay to attend our events yourself, please consider applying [7].

Finally, I would like to offer my deep gratitude to the whole of the NatSCA committee, and our team of excellent volunteers: Justine Aw, Glenn Roadley, Emma-Louise Nicholls, Sam Barnett, Natalie Jones, Jen Gallichan, David Notton, and Gina Allnatt. As always, I end with a special vote of thanks to our Treasurer Holly Morgenroth, without whom we would be lost.

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Museums as experimental test-beds: Lessons from a university museum

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Abstract

Resistance to change is an accusation that has anecdotally been thrown at museum curators, but in my experience, today's museum professionals have extraordinary capacity to be innovators and experimenters. Here I will describe why and how museums might want to establish formal strategies to develop themselves as places where innovative ideas and practices can be tested as part of their everyday operations. I will set out why museums might want to establish a publicly visible experimental philosophy, focusing on lessons learned from the activities of the Grant Museum of Zoology, UCL.

The benefits of innovation include advocacy, raised profile, and an enhanced visitor experience. I will discuss various models to embed experimental practice. These can operate at different scales, ranging from small visitor studies and pilots to large-scale interventions potentially engaging every museum visitor, but all contributing to an atmosphere where experimentation is encouraged and ingrained. In this atmosphere, it is crucial that there is understanding and planning that allows for failure – some experiments do not work, and that is totally fine.

Keywords: Innovation, experimentation, visitor experience, digital, higher education, university museums, research, failure

Introduction

In 2011, the Grant Museum of Zoology at University College London (UCL) reopened in a new, highly accessible venue at the heart of the university, positioning itself as one of the key public gateways to UCL. The intention was to develop the new museum as a place where innovative ideas and practices could can be tested as part of the everyday running of the museum (MacDonald and Ashby, 2011). This would involve inviting academic researchers to use the museum in their research, but not only the traditional specimen-based research that is the mainstay of natural science collections. We would collaborate with them to use the physical space of the museum – as a public attraction – to experiment with modes of digital and physical engagement, communication, pedagogy and museology *on our visitors*.

As I will demonstrate, this approach proved successful. It has become embedded in our practice throughout the years since reopening. Indeed, the concept of 'Museum = Lab' is a central strand of the strategic plan of UCL Culture – the wider department to which the Grant Museum belongs (UCL Culture, 2016).

This is a reasonably common philosophy among university museums, but here I will argue how and why this way of working could be of benefit to any museum. This is not a new philosophy, and the Grant Museum is certainly not alone in working in this way.

Motivations and Outcomes

What could a museum hope to gain by establishing an experimental philosophy? Why would they want to be innovators? Arguably, deciding whether being innovative is a good thing is not a difficult decision for most museums. Despite the stereotype, resistance to change is not a characteristic I have experienced in the museum sector. Museum people are creative, ideas people.

Being innovative comes with all sorts of benefits. I suggest that they come in three broad categories – advocacy, profile, and visitor experience. The three are linked.

Advocacy

Most museums today need to work hard to convince their funders to continue supporting them (see, for example, Mendoza, 2017). This is true whatever the organisational model. For example, in university museums we are effectively being squeezed from both sides – the Higher Education sector has less money, and the museum sector has less money. The short story is that managers at university museums should never forget that, at any given moment, someone in their senior management could well be wondering whether the value added by its museums is of greater worth than the solid cash that could be brought in if they converted all the museum spaces into classrooms. There are similar pressures in other kinds of museums.

With these pressures on resources growing, museums must do all they can to prove their worth to their funding bodies. I would argue that one of the worst labels that a museum could be given is 'old fashioned'. The continuation of funding just because funding has always been there is no longer an assumption that museums can afford to make.

Developing a reputation for being innovative is almost always a good thing in the eyes of those who make decisions about a museum's funding. The museum sector changes all the time, but being involved in directing some of those changes is an attractive prospect. Developing new ideas and sharing them widely simply looks good to your funders. They want to know what their investment is delivering. If a museum can demonstrate they have developed a new idea that is having genuine impact on the outside world – by that idea being adopted by other institutions, for example – then the funders can see the value of their funds.

Beyond the simple appearance of positive outcomes, working on formal academic research programmes has the potential for formal recognition of the impact (with a capital I) of the work in the real world. Universities have to undertake the periodic Research Excellence Framework (REF) exercise, and being included as a research partner in a REF case study is a fantastic advocacy outcome for a museum. Particularly as, to date, there have been relatively few such museum-linked REF case studies.

Profile

This is closely related to advocacy, but thinking beyond a museum's own funders, being considered innovative by others in the sector also has significant benefits. The Grant Museum is a small museum, with fewer than five permanent staff and a decent but unremarkable natural history collection. Fortunately, we have been able to develop a reputation as people with good, impactful ideas, and to contribute to the wider sector in as many ways as we can.

We enjoy a significant level of national press coverage (approximately 75 national features a year (e.g. articles in publications like *The Guardian*, *WIRED*, *Mail Online*, *The Times*, etc.; or features on BBC Radio 4 or television news)). Our activities are also regularly cited as examples of good practice by our peers in the sector, and we are invited to contribute to workshops and publications by bodies like The Museums Association or Arts Council England (more than might be expected for a museum of our size). I believe that this is in a large part down to us gaining a reputation for always being up to something: that something is always going on and we are always trying new activities.

This isn't just because we do have a lot going on, but because we devote a relatively large amount of time to sharing the practice we have developed through press releases, blogs, conference papers, and other networks. The philosophy of striving to be an experimental museum is that the experiment is intended to test a new idea for the wider sector. Success is not simply measured by whether the experiment 'worked', but on whether it goes on to influence practice elsewhere – is the idea adopted by

other practitioners? Central to that model is communicating both that the 'experiment' is taking place (though we may not always use that word), and the results. Indeed, the project can still be successful if the experiment fails, if in failing the museum can share useful lessons they learned. This requires allocation of resources to dissemination.

Visitor experience

Finally, a major benefit of testing innovative ideas and practices is that – when it works – the museum ends up with something exciting to offer their audiences. Public audiences do not always know whether something they are encountering in a museum is at the cutting edge of new practice (though they might, particularly when it is using emerging technologies). However, if they engage with something memorable in their visit, then that builds motivation for them to stay longer and to come back.

Some of the more successful experiments at the Grant Museum have resulted in visitor offers that we regularly see mentioned in five-star *Trip Advisor* reviews. We love objects in the Grant Museum, and so do our visitors, but it is very clear that our visitors really enjoy engaging with new ideas and new technologies as well as object-led displays.

In the Grant Museum, embedding a philosophy as an 'Experimental Museum' has contributed to a ten-fold increase in visitor figures over the last five years. These kinds of statistics contribute to our profile within the sector, and our ability to advocate for ourselves to our funders.

Innovative, or experimental?

So far, I have used the words 'innovative' and 'experimental' relatively interchangeably, but they are not entirely the same thing. The benefits above can be gained from being seen as innovative, but I suggest that they are greater if the museum is experimental. An experiment has the inherent risk of either not knowing what the results will be, or that the results you get are not the ones you expected. The point is: experiments can fail.

As it typically relates to museums, innovation involves the implementation of a recently developed idea. In the main, the implication is that the idea in question is already understood to be a good one, and even that the idea worked – it produced positive results, for example an enhanced visitor engagement offer.

While it's much, much easier to succeed in bringing in benefits in terms of advocacy if the experiment works, there is still a lot to be said in terms of visitor experience and profile-raising within the sector, and with audiences, for getting a reputation for being an experimental test-bed rather than just being innovative. There are probably ways of being innovative without being experimental – for example by bringing in new models of practice and engagement *after* they have been tested and found to be successful, but *before* they have become mainstream, but that is not the focus of this paper.

Establishing an experimental philosophy

The decision for the Grant Museum to work at being an experimental museum was a deliberate one – we actively set about seeking research partnerships and made projects very visible from the outset, so that other potential academic collaborators saw that we were open to proposals. We even designed the new museum space with this kind of work in mind.

The first thing we did, and continue to do, is *say* that we are an experimental test-bed. Every time we get in front of a museum or a Higher Education audience, or whenever we write a practice-based journal article or press release, we *say* that we want to act as an experimental test-bed. Such repetition of the message is key to getting the idea ingrained in stakeholders' opinion of you. This needs to happen from the top: strategic plans and senior management's communications need to reflect the philosophy if a museum's staff – and ideally its audiences – are to believe that they are an experimental test-bed.

What do museums have to offer?

The key way in which we adopt innovative experimental activity is to work with academic researchers, who are specifically employed to create new knowledge, and test new ideas. Much of this work has involved research into new models of digital engagement, testing whether certain ideas or hardware would 'work' with a public audience in a museum setting.

Museums and their staff have a number of things to offer academic researchers in an experimental project. Indeed, this kind of research would be potentially impossible without museum partners.

Chiefly, it comes down to space, audiences, and expertise.

If a research project is attempting to test whether a new idea, technological innovation, or model for engagement will actually deliver the outcomes it has been designed for, they will need test subjects. Doing this in the artificial environment of a lab or office is unlikely to provide reliable results; true success can only be evaluated 'in the wild'. It also requires unbiased participants, often coming in with no prior knowledge. If a new development is intended to work with a certain public audience, then it needs to be tested on that audience. Museums can provide academics with their 'guinea pigs'.

There are a number of ethical considerations in working with potentially unwitting members of the public that I will return to later, but many researchers struggle with finding enough people to include in their studies. Museums can pretty much guarantee that they can get an experiment in front of a real person. Likewise, if someone is testing how a certain digital platform will work in a museum environment, then they need a real museum in which to test it. Museums can literally open their doors to providing the real-world environments the experiments require.

Finally, museums have extraordinary expertise in their staff. Museum professionals are experts in public engagement, interpretation, communication, and exhibition design. While the project is in development, it is the museum's role to play the audience-advocate. Often, the academics on a research project will be seeking to test how people behave around a new digital development. They may be experts in building the digital platform and developing the software, but they may benefit from the museum staff's perspective on how visitors will encounter it in a museum setting, what their motivations are, and anticipate potential hurdles. This expertise is invaluable to the researchers.

Experimental case studies

Here, I present examples of previous projects the Grant Museum of Zoology, which operated at different scales but all contributed to an atmosphere in which experimentation is encouraged and ingrained. In such an atmosphere, it is crucial that there is understanding and planning that allows for failure – if the experiment does not work, all is not lost. You haven't bet your house on it, and you've never called it anything but an experiment.

These case studies are provided as possible models for how experimental working could manifest in museums, operating at different scales. The model for experimentation or study is intended to be the example, not the content of the projects themselves.

1. The simplest: A short-term visitor study

The Grant Museum allowed a post-graduate student to undertake a potentially risky visitor study: to enquire how best to display challenging objects and to communicate uncomfortable histories (in either museums or non-museum settings). The object they used was a respirator that was used to keep dogs alive during vivisection in the 1930s. The topic of live animal experimentation is a very difficult one, with the potential to upset visitors, and as such comes at some risk to any museum displaying it (particularly when it relates to the institution's own history with that subject).

By putting an object like this on display, the museum risks its reputation, as it could be interpreted as supporting animal cruelty (whatever its official stand on animal experimentation). How can museums discuss this history without alienating visitors, or risking their own reputations?

The study sought to engage small numbers of visitors by testing two different modes of interpretation, which used different approaches to communicating the history of the object. Visitors were engaged in a structured interview about their reactions to the object and the different interpretations. The presence of such a contentious object in the museum in these circumstances avoided the reputational risk, as the uncomfortable issue of vivisection was cushioned by making it very clear that the study was seeking people's views – visitors knew that the topic was under study. In fact, such conversations have significant potential to enhance the visitor experience as their views are being sought to influence broader practice, and if they do have strong views on the topic, then they could feel that their feelings are being taken into consideration (Fewery, 2014).

For the museum, the costs of allowing the researcher to involve visitors in the study are minimal. All that is needed is some space, some simple signage (that could even be provided by the researcher), and – as with all the examples provided – for the museum to ensure the appropriate research ethics measures are in place (see below).

2. Pilot study or focus group

This involves the museum recruiting a sample of the desired audience from among its visitors to attend a facilitated workshop with a specific research goal in mind. It will often require the group to attend a series of meetings over time, in order to measure change in the attendees' behaviour or understanding. At the end of the project, it is possible that the research could have developed a product that the museum could use as a broader visitor offer.

At the Grant Museum, we worked with an academic (Angeliki Symeonidi) from the UCL Institute of Education, who was studying the pedagogical impact on a child's learning when they were involved in the development of an educational video game, set in a museum. The Museum advertised the opportunity to be involved in developing a Grant Museum-based computer game to its family audiences (through mailing lists). The researcher managed the communications from interested parties, as well as the incentives for attending.

For a series of workshops during which the video game was developed, the museum offered the gallery space to be used out of opening hours, and provided feedback on the zoological and museological content of the game. The researcher interviewed the participants each week, and made observations from recordings of the sessions in order to measure any impact on their learning.

The fact that the museum advertised the opportunity through its mailing lists also meant that the project was visible to a far wider audience than just those few who actually wanted to take part. This contributes to building a museum's reputation for such activity.

There also remains the possibility that the game that was produced by the group could be 'adopted' by the museum (with some investment) to be offered to visitors more generally. This possibility arises regularly with experimental museum projects – in order to test whether a new technology works as part of their research, for example, they may have to build a fully operational product. If the museum likes what it sees, then it can roll it out as part of its standard visitor offer.

In order to do this, it is important to agree in advance who owns the intellectual property of any new innovations, and whether the museum has the right to use them beyond the conclusion of the research (and under what terms). Partners should also agree what happens if other institutions want to adopt the idea – do they have to start from scratch, or does the team want to share the inner workings? What support would the partners be willing to provide other museums interested in the idea, and how would such impact be measured and recorded? These kinds of data can prove very useful if the project does end up being included as a REF case study, or even just to show funders what impact the museum is having through its experimental work.

3. A live test in the gallery

For experiments that rely on testing how museum visitors behave around new digital innovations or models of engagement, or whether a certain innovation is enhanced by being incorporated into a museum environment, researchers could seek to temporarily insert their idea into a gallery. This allows them to see how their innovation works 'in the wild', on the specific audience that it is intended for.

These tests can operate at vastly different scales, ranging from a few days to several years. Small, short tests in a live gallery situation can inform the feasibility of a larger study. In the past year, we have worked on smaller projects with both Augmented Reality (AR) and Virtual Reality (VR).

The former was a post-graduate student project with UCL Computer Sciences. The student's task was to build and test a functional AR app to meet an identified need (so this project could be considered as a pedagogical exercise as much as a research programme). They sought guidance on a real-world need in a natural history museum which could potentially be solved by AR. We suggested that they augment some of the skulls and skeletons that we believed visitors had difficulty interpreting on their own – for example, where do the eyes, trunk, and ears connect on an elephant skull?

The student developed an app that would layer these features onto the object when the camera on a smart device was held up to the specimen. This involved a number of meetings with the student, and access to the specimens on display, as well as guidance on the zoological content of the digital models they created. The plan was then to test this in the gallery with our visitors. This final testing phase did not happen, and this is discussed further in the pitfalls section.

With the VR project, a Professor of Protein Biochemistry (Matilda Katan) approached us to test whether museums were a suitable place for visitors to

use VR technology. The rise of Virtual Reality has been well documented, and its use in museums and other cultural settings is on the rise. However, the sector may need to consider that museums are places that parents and carers might be visiting in order for their children to escape from 'screen time'.

Matilda Katan had been working with a VR software development company to produce a VR tour of an animal cell for use in educational settings, such as schools. Her team was interested in whether visitors to museums – which are full of stimulating *physical* realities – were interested in opportunities to explore virtual content on a topic linked to the museum's collection, or if these experiences are best kept in the home or school, for example.

Figure 1. A visitor taking part in a virtual reality experiment in the Grant Museum. Image © UCL / Matilda Katan.

Museum staff with a background in learning provided feedback on the length and pitching of the content on the VR tour to the museum audience they were targeting, which led to some changes before it was tested in the gallery. The researchers offered the VR experience to visitors during several of our pre-existing family activity days (alongside our own standard activities), and interviewed users about their experience. This is being used to inform the applicability of such products for museum settings (see Katan, 2017).

While the activity days as a whole were advertised widely, we didn't promote the VR experience specifically, in order to manage expectations. This is because we were aware that the number of VR headsets and the length of the tour meant that demand could easily outstrip supply. Also, if people specifically came to the museum in order to experience the VR app, it could bias the study into whether museum visitors in general thought VR was appropriate for museums.

Aside from these shorter projects, which lasted a few months and targeted specific groups of visitors on specific days, we have also run long-term major interventions aimed at accessing ALL of our visitors.

QRator was a project which ran from 2011-2016 and tested models for user-generated content in museums, following the trend for democratising the museum experience for visitors. Ten iPads were mounted on specially developed object-based displays, which asked visitors to share their thoughts on questions around science in society or how museums should operate, through a digital conversation (see Bailey-Ross et al., 2016). At the time, it was only the second time that iPads had been installed in permanent museum displays (and arguably the first that actually relied on the specific features of iPads), and was considered 4-5 years ahead of the 'adoption curve' for the sector (i.e. that the concept was likely to be widely adopted by the sector in 4-5 years) (Johnson et al., 2011).

As well as being a significant visitor offer in the gallery, it was also the centre of two PhDs: one of which studied the behaviour of visitors around 'social interactives' (museum interactives which essentially borrowed conversational models from social media); and one on the technological aspect of how such products are built.

Although the in-gallery phase of the QRator project was only initially anticipated as lasting a year, the overwhelming success it achieved encouraged us to keep it running for five years. Visitors regularly cited it as one of the highlights of their visit, and it garnered significant interest from the museum sector, with fellow professionals coming to see it from around the world on an almost weekly basis. Parallel systems were eventually rolled out to a national and an independent museum as part of the study. In the end,

the success of the project brought to light pitfalls that we had not anticipated (see below).

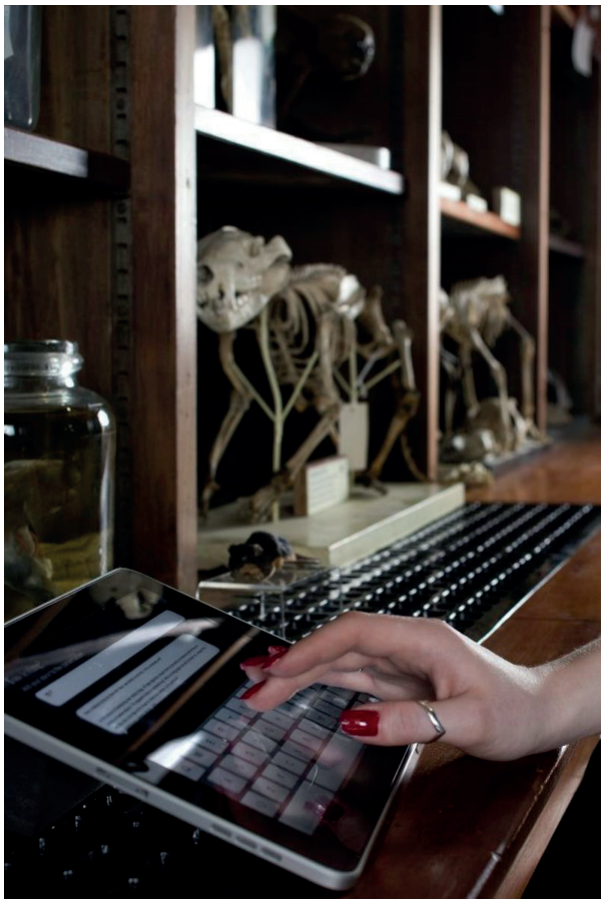

Figure 2. QRator was a major research programme into user-generated content in museums, and how visitors behaved around 'social interactives'. Image © UCL.

Pitfalls

Failure of the product or idea

As has been mentioned, whatever efforts or expertise have been invested in a new idea, failure is a possible outcome of experimental working. The museum must be willing to deal with the consequences of an innovative idea not delivering on its aims. Collaborating on research is an inherently risky undertaking, particularly when technology is involved. Oftentimes, there will be multiple stakeholders driving the project: the museum itself, audience focus groups, the researchers, and the technology developers.

As with any partnership project, objectives may not be completely aligned between the different stakeholders, and lines of responsibility can be complicated. We have worked on projects where the developers reported to the researchers (as they were the ones paying), which left us with limited power to insist on changes to products. This can lead to the museum having to decide whether to allow an idea to be tested on their audiences, when the museum staff are certain it will fail. This is a very difficult situation to plan for, but clear Memoranda of Understanding are vital, and I would advise retaining the option of refusing to allow the idea into the gallery if you feel it will diminish the visitors' experience. Be specific about what resources the museum is willing to contribute, and think carefully about what you are signing up for.

Visitor expectation also needs to be managed: museums should go to lengths to communicate that visitors are being involved in an experiment, and wish to learn from their experiences – both good and bad. We have tested truly awful digital products in the gallery, and could do so without diminishing the visitors' opinion of us by being extremely clear that the purpose of having the product in the gallery was to see if it worked. Them telling us that it didn't work ended up being a positive experience for the visitors, as they could see that their input was contributing to academic research.

Failure of completion

Another risk of partnerships where partner objectives do not completely overlap is that once the academic aims have been completed, the realities of taking the project to the point at which it can actually affect the visitor experience can, in our experience, be deprioritised. This is perhaps particularly true with student projects which focus on the *development* of a technological innovation, rather than the users' experiences.

Research teams may enter a project with every intention of both building and testing a new idea, but the realities of unfolding timescales may mean that they do not reach the final stage. This is bad news for the museum, as it is through the actual live-testing and implementation that the three benefits of profile, advocacy, and visitor experience are likely to bear fruit.

We have engaged in a number of student products where the design and development phases have overrun, and, while their projects suffer from their failure to get a user perspective for their assessments, the reality is that once their submission deadline has passed, they are unlikely to be willing to continue to deliver on putting it in a live gallery environment. We

are yet to find a solution to this, beyond stressing the reasons why the museum is investing in a project and hoping for the best. Museums without a strategic reason to support student research may be best to avoid technology-based student projects with short timescales (e.g. Masters' programmes).

The problem of success

Success can come at a cost – what does a museum do if the experiment far exceeds its expectations? Does it have the resources to continue deploying the technology after the research has finished?

As was mentioned, the QRator project was far more successful than we had anticipated, and we found that its presence in the gallery was a significant contributor to our visitors' experience. This means we had real motivation to keep it running.

With technological experiments, it is important that the partners are clear who is responsible for its maintenance. Depending on the museum's digital expertise, it is likely that the researchers are either directly responsible for the back-end development and maintenance, or have commissioned support for this from an outside company.

All research programmes are time-limited – when the research programme has achieved its academic objectives, or reached the end of its funding, the museum must decide if it can continue to support its deployment. At this point it would stop being an experiment, and simply become a visitor offer.

With QRator, the researchers decided to extend the original remit of their enquiries, as the project was continuing to produce invaluable data, but it did eventually come to an end. We decided to keep it in the gallery only as long as it continued to function. Once it was removed, visitor comments showed that they were disappointed that it was no longer available, and so the museum worked to communicate that the experiment had come to an end, and to share the project's findings.

Ethics

This isn't really a pitfall, but it does need careful attention. Using information gathered from public visitors in academic research requires adherence to ethical guidelines, beyond standard data protection legislation. If partners in a project team belong to a research institution (such as a university), then their research will need to be approved by that institution's ethics boards, as well as the museum's (if it has one). Ethical guidelines for academic research typically make a distinction between 'evaluation' and 'research', and it is important to know whether an experiment is one or the other (evaluation is typically beyond the scope of ethics boards).

Museums undertaking research involving their visitors should have procedures to ensure any experimental projects fall within the ethical standards of their research partner organisations. At the simplest level, this could just be to ask to see the confirmation from that institution's research ethics board that the researchers have had their research proposal approved.

Discussion and Conclusions

The Grant Museum of Zoology at UCL is a small museum with an unremarkable collection, but it has found significant success (for example, winning multiple awards and dramatic increases in visitor numbers) in part due to its efforts to position itself as a venue for experimental working. We are both active in our recruitment of potential academic research partners, and welcoming to those who approach us directly. We have found that the financial costs are low (because we ensure they are covered by the research partners), and we manage staff resourcing by agreeing early on what the museum staff's involvement would be in a project.

Experiments can fail, and museums engaged in experimental practice must be prepared to accept and expect failure. With that said, museums should not be afraid to say no to proposals if they think the experiment *will* fail. The museum professional's role in most museum-based academic research of this kind is to provide expertise in what to expect from visitors in a given setting. As such, they should trust their instincts and reject some proposals before they are tested. There are pitfalls to be aware of and anticipate, but some of those are hard to mitigate for. Clear partnership agreements are vital.

Experimental working is not the exclusive remit of university museums. Museums of all kinds can benefit from these practices, and there are universities and researchers out there looking for places in which to experiment.

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A lure to take the biscuit: A *Stegobium paniceum* pheromone trial at the Royal Horticultural Society herbarium

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Abstract

There has been no commercially available pheromone lure in the UK for monitoring biscuit beetle for many years. The Royal Horticultural Society's herbarium at Wisley has trialled a new lure to attract male *Stegobium paniceum* (Linnaeus, 1758).

The RHS herbarium, although annually frozen, still suffers from an infestation of *Stegobium*. A seven-week trial using Stegobinone lure traps was undertaken across the herbarium collection area. Control traps, without lures, were placed close to lured traps. Many more *Stegobium* were attracted to the traps containing the lures than the control, with beetles continuing to be caught long after the manufacturer's recommended replacement period. The lure has proved highly effective, and the trial at the RHS has identified the epicentre of the infestation, enabling targeted treatment.

Keywords: biscuit beetle, drugstore beetle, Stegobinone, Stegobiene, pest control, Hiresis®.

Introduction

The herbarium collection at the Royal Horticultural Society (RHS) Garden Wisley specialises in cultivated plant diversity. It is home to over 83,000 specimens of pressed plants, numerous plant portraits, dried fruits and seeds, and also provides an environment in which *Stegobium paniceum* (Linnaeus, 1758) (biscuit beetle or drug-store beetle), the traditional pest of dried plant collections, thrives. Due to pest treatments in the past, in which specimens were painted with mercuric chloride, the older collections remain unaffected by the beetles, while the more recent specimens, lacking pesticides, are frequently damaged by the beetles.

A synthetic analogue of Stegobinone, the female *Stegobium paniceum* pheromone, has been produced and is commercially available in both the United States and Japan. Samples of the synthetic pheromone were received by the third author (JS) at a Trade Fair, and a trial was formulated to see if it was effective. Many of the earlier attempts to reproduce the pheromone had failed to lure sufficient quantities of the adult male beetles, and proved too costly to manufacture, so were taken out of production. The trial took place at three sites known to harbour *Stegobium paniceum*: a commercial bakery; a pet food manufacturing plant; and a museum (the RHS herbarium collection).

Stegobium paniceum: the biscuit or drug-store beetle

This beetle was known to the ancient Egyptians, and has been found within entombed burial materials, some dating to over 4000 years before present. Panagiotakopoulu (2003) found the remains of 17 *Stegobium* in a well-preserved deposit of wheat from a Middle Kingdom tomb at el-Gebelein, Egypt (earlier than 2049 BCE). Later, Elizabethan explorers played an interesting role in its spread, as it was conveyed around the world in sailors' biscuit rations on-board ships. Known as '*hard tack*', this biscuit broke many a sailor's tooth. Made primarily of flour and baked three times, this nutritionally poor food was favoured by biscuit beetle. *Stegobium* are particularly fond of starch, and bore into dried vegetable material, the starchier the better (Aitken, 1975) (see Figure 1). Living in symbiosis with a yeast, adult females secrete a layer of the yeast fungus on the outer surface of their eggs; it is passed on to the emerging larvae during hatching, and it is carried internally in a special organ. This enables the beetles to survive on a range of nutritionally poor foods. Each female lays about 60 eggs singly and, given warmth and high humidity, the life cycle can be rapid: 20 weeks at 20°C, 12 weeks at 25°C, and 6 weeks at 30°C (Adams, 1993; Lefkovitch, 1967; Pinniger, 2015: p.31). A study by Rumball and Pinniger (2003) indicated that wild strains of *Stegobium* (as opposed to those kept under laboratory conditions) are likely to be far more tolerant of cold conditions (Solomon and Adamson, 1955), and this can seriously affect any temperature measures taken for pest control. The adults are short-lived and it is the larvae that do the most damage to collections. Due to their high starch content, herbarium specimens have habitually been infested by *Stegobium* (Croat, 1978; Harvey, 2001). More information and illustrations of the beetle can be found in Pinniger (2015: p.31), Rumball and Pinniger (2003), on the website of the Natural History Museum (Natural History Museum, 2014), the website 'What's Eating Your Collection' (Birmingham Museums and Art Gallery, n.d.), and on the Central Science Laboratory reference card IC/286 (Adams, 1993).

Most stored-product beetles produce pheromones to attract mates. *Stegobium paniceum* females lure males using an attractant pheromone, Stegobinone (2,3-dihydro-2,3,5-trimethyl-6-(1-methyl-2- oxobutyl)-4H-pyran- 4-one) (Kuwahara et al., 1975). Kodama et al. (1987a; 1987b) (including a co-author from Fuji Flavor Ltd) studied the synthesis of Stegobinone, particularly the discovery of isomers that inhibit or reduce a male response. This resulted in a very early pheromone trap being sold commercially, the Fuji Trap 87, which was trialled at RBG Kew (Rumball and Pinniger 2003)). Although effective, the synthetic pheromone produced in both this and the other early anobiid beetle traps made by AgriSense in 1996 proved too expensive to synthesise for the relatively small quantities required by the public to make it commercially viable (Rumball and Pinniger, 2003; White and Birch, 1987; Mori, 2010). Fuji Flavor Co., Ltd have recently been able to produce a synthetic analogue of this, known as Stegobiene (2,3-dihydro-2,3,5-trimethyl-6-[(1E)-(1-methyl-1-buten-1yl]-(2S, 3R)-4H-pyran- 4-one), which is said to be a longer-lasting mimic (Fuji Flavor Co., Ltd., n.d.). It is this, the Hiresis® trap, that has been trialled here.

Figure 1: Damage caused by the biscuit beetle. Note the frass and damaged petals of this Lupinus L.. Image: Yvette Harvey © RHS 2017.

Preventative conservation measures at Wisley

The collection is housed within the Laboratory at RHS Garden Wisley, and contained within a suite of rooms at the back of the building that were built on top of an old lecture theatre. The collection based at Wisley commenced in the early 1900s, primarily with specimens of British plants made by student gardeners. This was housed in the first floor Science Library, until it was later moved downstairs and contained within wooden cabinets. Historic material

was donated to the collection in the 1930s. By 2006, metal cabinets replaced the old, and an annual freezing regime was initiated to reduce numbers of *Stegobium* infesting the collection.

Conditions are cramped, and the collection area is shared with staff. The building has single-glazed windows, water ingress issues, and there are considerable environmental fluctuations (see Figures 2 and 3). The heating is centrally controlled, and, as with similar old buildings, the herbarium has unlagged pipes that carry hot water throughout the collection area. The heating is switched on and off every 12 hours from October to May (Figure 3), and there are similar temperature fluctuations during the summer as the building lacks air conditioning (Figure 2). Staff working within the collection area require an appropriate temperature during the winter and, as a

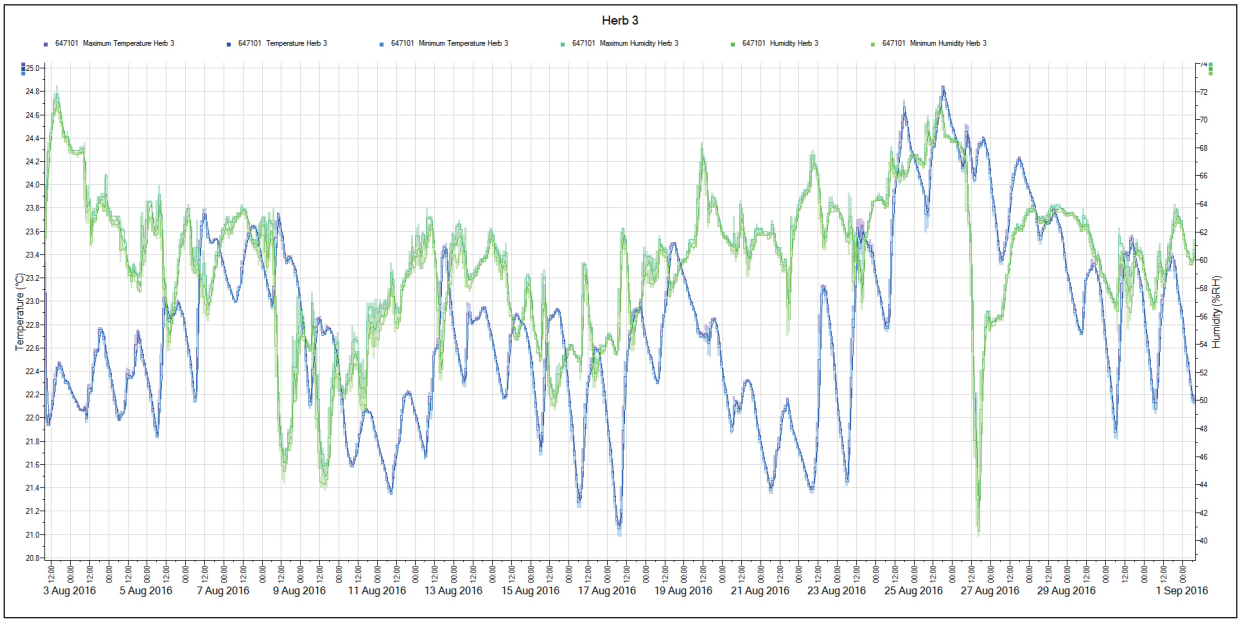

Figure 2: Temperature and humidity readings during part of the trial, August 2016. Heating is switched off during the summer months.

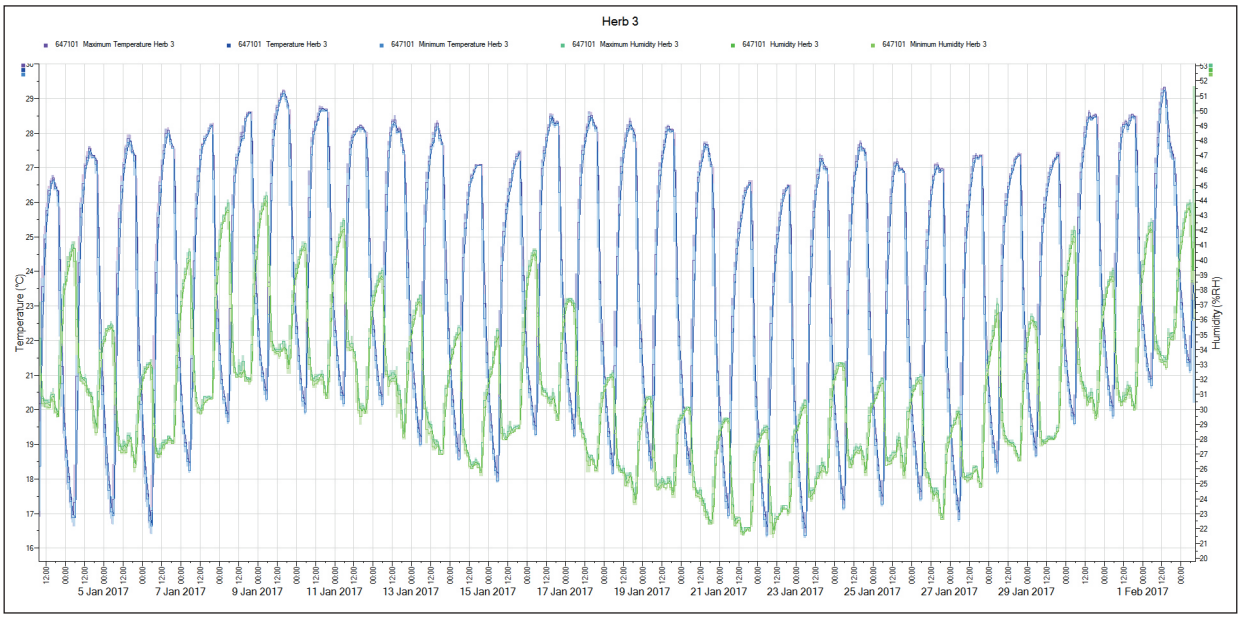

Figure 3: Temperature and humidity readings during January 2017. Heating is switched on between early morning and late afternoon, and off during the night.

consequence, adjust the temperature of the radiators as required.

A number of measures have been undertaken to reduce/discourage insects. Food is banned from the herbarium, and drinks are only permitted in sealed cups. Specimens are bagged within the cabinets to prevent easy access to a wandering insect, and the cabinet doors have tight seals. All material entering the collection is frozen on arrival and before finally being incorporated into the collection. The entire collection is frozen on an annual cycle, including the backlog of un-accessioned material stored on top of the cabinets. Each freeze treatment is at -30°C for 72 hours or more. Floors and cabinet interiors and exteriors are sprayed with a synthetic pyrethroid (Vazor® Cypermax Plus) when numbers of insects found in adjacent traps indicate a need for treatment.

The pheromone trial

Although they don't pose a direct threat to human health, biscuit beetles can be a significant pest in the food industry and are also damaging in museum and herbarium collections (Pinniger, 2015: p.31). What has been lacking until now is a widely available pheromone to monitor sexually active males before they encounter a female. Having received samples of the Hiresis® trap from Fuji Flavor Co. Ltd., John Simmons (JS) formulated a small trial to establish if the new pheromone worked effectively. For this, JS selected three different sites: a large bread bakery, a large animal feed plant, and a museum collection. All sites were known to harbour *Stegobium paniceum*. The trial was undertaken over a six-week period at these three sites, during August and September 2016.

The Hiresis® trap comprises a pheromone analogue contained within a small capsule that has a plastic upper cover and paper base, stuck to a glued cardboard trap. It was decided to discard the manufacturer's cardboard trap in case this was the lure rather than the actual pheromone. Instead, lures were stuck on alternative commercially available crawling insect monitor glue pads, held within a commercially available hanging frame (the Demi-Diamond trap). The frames were not necessarily hung as recommended; some were placed flat on surfaces. At site 1, the bakery, the pheromones were placed as recommended by the manufacturer, with the paper surface downwards; at site 2, the pet food manufacturer, half the lures were placed the correct way, and half upside down; at site 3, the museum collection, they were all placed upside down. This was to test if the lure still worked even if placed in a non-conformist way. Identical traps lacking the lures were placed in close proximity (circa 1 metre away) to the lured traps (see Figure 4), again, to check if the trap itself was the lure and not the pheromone. 20-30 traps were placed in each site, in 10-15 locations.

During the trial period traps were checked weekly and cumulative totals for each trap were made.

Figure 4: Paired traps, one with a lure and one without on top of a block of cabinets at The RHS herbarium (site 3). Image: Yvette Harvey © RHS 2017.

Results and observations from the RHS herbarium (site 3)

The results seen in Table 1 demonstrate that a noticeably larger number of *Stegobium* were attracted to the lure traps than to the control traps without lures. The trap captures within the collection rooms have also indicated where the epicentre of the infestation is likely to be (see Figure 5). This enabled RHS staff to target specific areas for treatment. It should be noted that there were a few beetles found on the traps without the pheromone, but the assumption is that they were just trapped as an insect would be caught in a normal blunder trap.

The RHS has kept both lured and control traps in situ, undertaking quarterly trap counts, and at the time of writing, 11 months from the start of the trial, the lure traps are still attracting beetles (Figure 6). This is considerably longer than the manufacturer's recommended lure replacement period of one-month.

As seen on the graph (Figure 7), traps are not functioning as an effective control, since the catch numbers are still escalating and are yet to plateau out or drop. These traps will continue to monitor the

Table 1. Results from pheromone (blue columns) and non-pheromone traps (white columns) at the RHS herbarium during the trial period.

Trap	05-Aug		12-Aug		19-Aug		30-Aug		02-Sep		12-Sep		16-Sep	
1	0	0	1	0	3	0	4	0	4	0	4	0	5	0
2	0	0	0	0	1	0	2	0	2	0	4	1	4	1
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	1	0	1	0	3	0	4	0	4	0	4	0
5	0	0	0	0	0	0	0	0	0	0	0	0	1	0
6	0	0	3	0	4	0	11	0	13	1	15	1	18	1
7	0	0	0	0	0	0	0	0	1	0	1	0	1	0
8	0	0	0	0	0	0	0	0	1	0	1	0	1	0
9	0	0	0	0	0	0	0	0	1	0	1	0	1	0
10	0	0	1	0	1	0	1	0	1	0	1	0	1	0
TOTAL	**0**	0	**6**	**0**	**10**	**0**	**21**	**0**	**27**	**1**	**31**	**2**	**36**	2

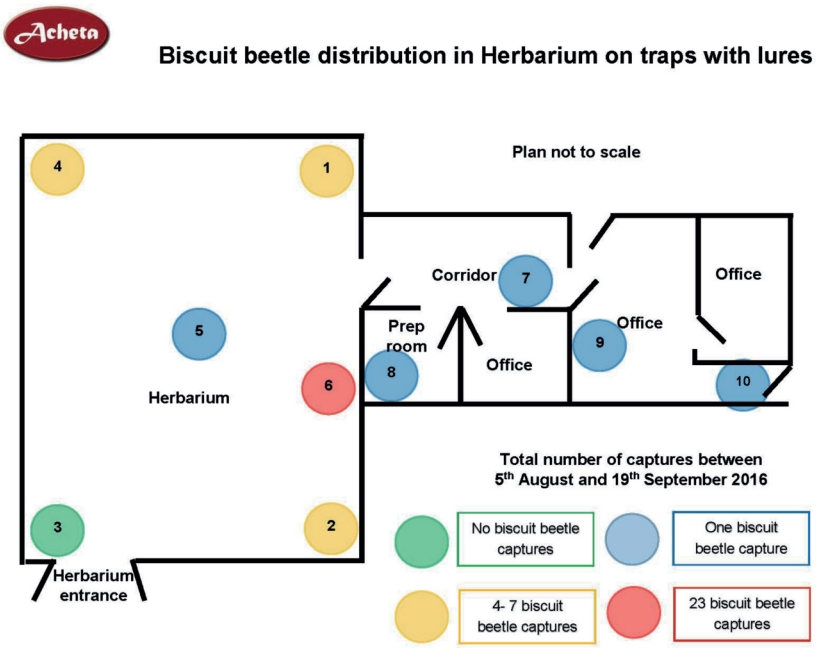

Figure 5. Map of the collection area showing where traps were placed and the hot-spots of insect activity, indicated by the numbers trapped. © Acheta consulting Ltd.

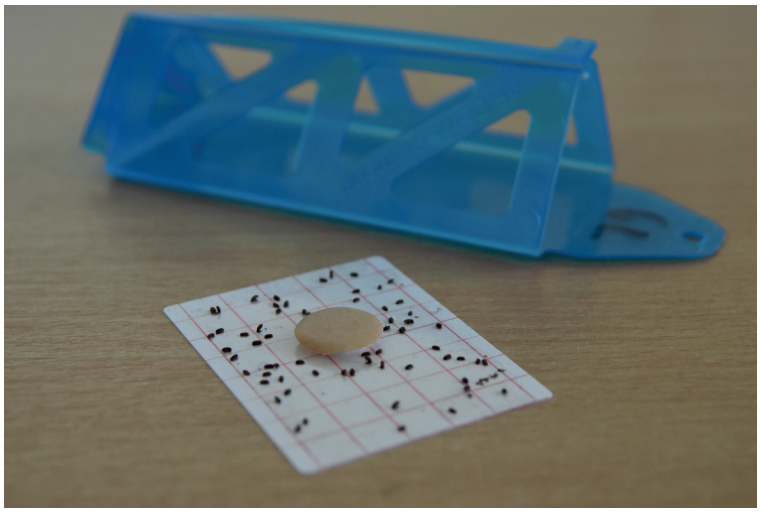

Figure 6. Sticky pad covered with Stegobium at The RHS herbarium. Image: Yvette Harvey © RHS 2017.

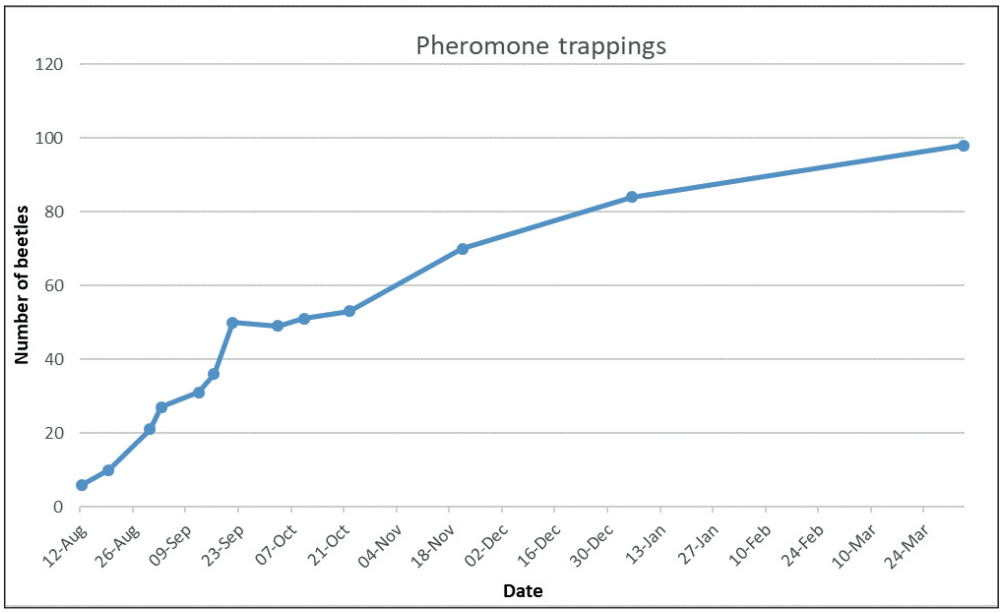

Figure 7. Results from lured traps at the RHS herbarium, during and beyond the trial period (aggregated data).

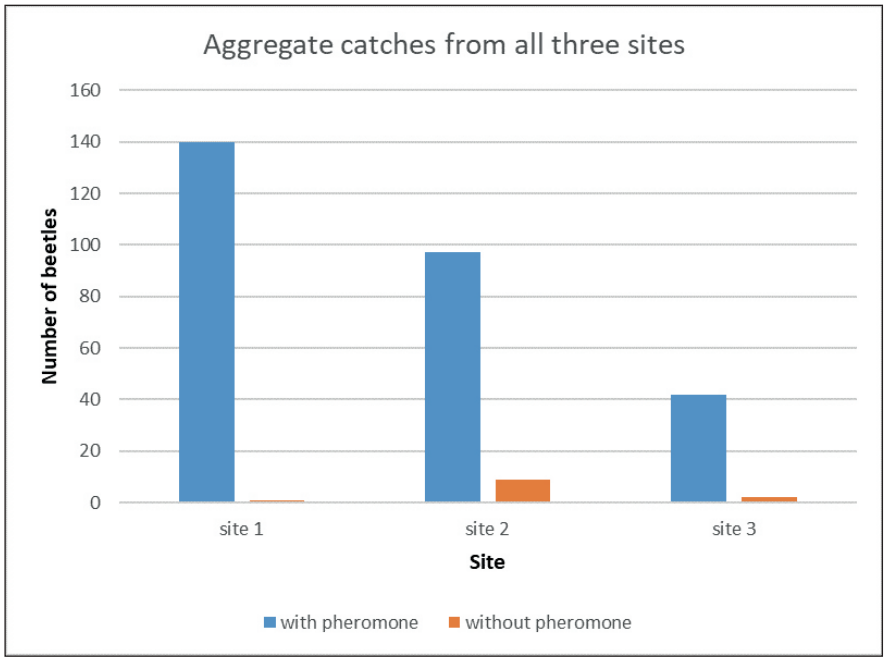

Figure 8: Comparison of catches from all three sites. Site 1 - Bakery (11 lures); site 2 - animal food manufacturing plant (15 lures); and site 3 - RHS herbarium (10 lures).

situation until the RHS herbarium collection is moved into a new storage facility, planned for 2020/2021 (all material moving to the new facility will be decontaminated prior to installation). Looking at additional beetles per trap after the trial finished, fewer beetles were trapped over the winter months than during the late summer months, when daytime temperatures can reach 28°C in parts of the herbarium due to the heating pipes within the collection area. This may have been as a result of the floors and cabinet tops being sprayed with a synthetic pyrethroid, Vazor® Cypermax Plus in the month following the end of the trial. Interestingly, *Stegobium* were the only insects present on the traps, as opposed to the mixture that is normally found on the herbarium's blunder traps.

Comparison between sites

The graph illustrating the aggregate catches across sites (Figure 8) clearly demonstrates the effectiveness of the pheromone monitoring traps at all three sites. The bakery (site 1 with 11 lures), had particularly high numbers, with the majority of beetles being found in the vicinity of the bread cooling plant. It is likely that this is due to less stringent cleaning in this area. Similarly, high numbers of beetles were trapped at the animal food manufacturing plant (site 2 with 15 lures). This site does not have rigid cleanliness regulations as for human consumption, so the beetles have been able to thrive in accumulated food debris.

Conclusions and further work

Although this trial is too small to be statistically analysed, the results strongly support that the Stegobiene lure works effectively and can be used to monitor the presence of *Stegobium* and highlight activity hot-spots within a museum collection or building. This new lure will hopefully enable Integrated Pest Management (IPM) staff to undertake monitoring across stores and buildings more easily, highlighting *Stegobium* hotspots and improving targeted treatment. However, at the time of writing, this product was only available from the manufacturer in Japan and through Insects Ltd. in the USA. Contact has been made with a number of UK-based pest control companies to see if is possible for them to stock Hiresis® traps in the UK and/or Europe.

Footnote

Unfortunately, there is a complication with the use of pheromone lures for pest control in Europe. In May 2017, the European Commission discussed at the 'Standing Committee on Biocidal Products' a proposal for a European Union (EU) Commission decision on the status of lured monitoring traps under Article 3(3) of the EU Biocidal Products Regulation 528/2012 (BPR) (Council of the European Union, 2012), and whether monitoring traps using an attractant were to be considered Biocidal Products.

The Commission advised the meeting that it would not take a decision on monitoring traps under Article 3(3), and that this would be left to each Member State to decide on a case by case basis and take control measures as appropriate. In the UK, the HSE considered this in June 2017. The position previously established under the Biocidal Products Directive 98/8/EC (BPD) is that traps purely for monitoring purposes to assess the necessity or success of pest management measures, clearly labelled, sold and used as such, are not within scope of the Regulation, and this will remain the UK position whilst they consider this further.

Acknowledgements

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Destructive sampling natural science collections: An overview for museum professionals and researchers

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Abstract

There are many reasons why museum collections may be used for destructive sampling, from DNA and isotope analysis to radiocarbon dating. The process is invasive and destroys a part, or all, of the specimen. This can result in reluctance by museum staff to allow specimens to be used in particular types of scientific research. We will present some of the motivations on both sides, but argue that the benefits of destructive sampling can outweigh the risks. Many analytical methods have improved dramatically in the last 30 years, requiring smaller sample sizes. With a focus on destructive sampling for genetic analysis, we will also present some examples from the literature where DNA from museum and archaeological specimens has greatly aided the reconstruction of a species' evolutionary history as well as enriching our understanding of the object sampled. In addition, we highlight the need for museum staff to understand exactly what researchers are asking for, and for researchers in turn to understand museum procedures. We include an example of a Destructive Sampling Policy and a Destructive Sampling Request Form, for institutions to adapt for their own use.

Keywords: DNA; Radiocarbon Dating; Destructive Sampling Policy; Destructive Sampling Request Form

Introduction

Museum natural science collections hold a wealth of information. From recording and portraying the incredible biodiversity of life on the planet to the historical distribution of local species, there is an enormous amount of knowledge to be gained. In addition, collections comprise an invaluable resource of hidden data that is often unexplored but that can be used for research purposes. This includes not only external data (such as morphometric information) but also information from within the specimen: DNA, proteins, radiocarbon, chemical isotopes, and mineral chemistry. Much of this information can only be unlocked by taking an invasive sample from the

specimen. This is known as 'destructive sampling', whereby a part or the whole of a specimen is destroyed to provide information. Museum professionals are keen for their collections to be used for research, but a misunderstanding of the full requirements of researchers and the impact on their collections can result in missed opportunities.

For the museum professional, there may be several concerns regarding destructive sampling. Much of the readily available literature relating to destructive sampling focuses on sampling for DNA extraction. Within this literature, the discussion is dominated by instructions on how to care for specimens to limit degradation. For example, one chapter in the *Care and Conservation of Natural History Collections* (Carter and Walker, 1999) is dedicated to 'Genetic Material' (Brown, 1999), yet this focuses solely on the preservation of DNA in a variety of specimens. Spooner and Russ (2014) also provide a whole chapter on 'Curating DNA Specimens', outlining useful information for the museum professional regarding the fragility of historic specimens and the importance of destructive sampling today. Although useful for collections care to enable future research, neither of these examples provide clear guidance for evaluating destructive sampling requests. Other publications outline more detailed methodologies for sampling specimens. For example, Junqueira et al. (2002) describe the removal and destruction of the wings of flies after washing museum specimens in distilled water. de Moraes-Barros and Morgante (2007) also describe destructive sampling of the skins of three-toed sloths (*Bradypus variegatus* Schinz, 1825 and *Bradypus tridactylus* Linnaeus, 1758), successfully extracting DNA from small, dried fragments (1.5cm x 0.3cm) (de Moraes-Barros and Morgante, 2007). It is also possible, in some cases, to sample museum osteological collections without externally damaging the specimens: Wisely et al. (2004) extracted small samples of bone (10-20mg) from inside the nasal cavity of 72 specimens of black-footed ferret (*Mustela nigripes* (Audobon & Bachman, 1851)). They achieved a high success rate of DNA sampling, whilst minimising visible damage to the specimens. These few examples illustrate different methods used to sample specimens, but also highlight that methods vary based on the specimen, research question, and researcher. Whilst it is helpful to know how specimens are sampled, there is still a lack of practical guidance that the museum professional may turn to when faced with destructive sampling requests.

Along with a lack of accessible, clear, published guidelines for museum professionals, there are other reasons why there may be apprehension about destructive sampling. A museum's main role is to preserve collections, not destroy them. It can sometimes be difficult for the museum professional to know how to assess requests for destructive sampling as it may not be clear exactly what the researcher is requesting or why. Often, research requests are written using detailed, highly specialist language, which can make them difficult for museum professionals with expertise in different areas to understand, let alone evaluate. Furthermore, for very rare or precious specimens, curators may receive requests from multiple research groups with similar objectives. At this point, it can be exceedingly difficult to select a proposal based on merit. Finally, requests may be treated with caution, especially if the museum holds specimens that have undergone previous sampling that has resulted in damage that may appear extreme by today's standards (Figures 1 and 2).

Figure 1: Incomplete femur of a human, Homo sapiens Linnaeus, 1758, from Bob's Cave, Kitley Estate (PCMAG:KBC162). Five large holes were drilled into the specimen for accelerated mass spectrometry (AMS) in the 1990s. Analysis dated this bone to approximately 5,035 years before present (Chamberlain, 1996). Image: Plymouth Museums, Galleries and Archives.

From the perspective of a researcher, museum and archival samples are an incredibly valuable resource for the study of diverse biological processes. Researchers often lack the opportunity to collect fresh material and rarely have access to distant species, both spatially and temporally. Museum specimens provide an exception, and natural science collections can often provide good insights into ecological and evolutionary change over time (Tin et al., 2014). Considering sampling for genetic information, many objects in museum collections retain DNA, primarily natural science specimens, but also material in archaeological, ethnographic, and even library collections (Fiddyment et al., 2015). Exploiting this genetic information can provide unusual insights into an object that would not be possible without destructive sampling.

The sometimes-differing objectives of museum professionals and researchers, coupled with the speed of technological advances, highlights that a framework for supporting meaningful dialogue between both is necessary. Even where research is actively part of a museum's agenda, it may sometimes be challenging for researchers to effectively convey the implications and aims behind their proposal to museum staff, highlighting a need for better communication. Additionally, researchers are often unaware of museum procedures or what collections are available to them. Coupled with this, the role of a museum is to preserve the long-term value of their collections (Wisely et al., 2004). As research improves, and in particularly the invasiveness of destructive sampling procedures changes, a legitimate concern for museum professionals is whether to allow sampling with existing technologies rather than to wait for the development of less destructive approaches. As a result, even the most active of collaborations can be challenged by the need to address the requirements of researcher and museum professional in parallel.

We suggest there is a strong need for (1) a better understanding of how specimens are sampled and the importance of museum collections in research, (2) clearer communication between researchers and museum professionals, and (3) good practice methods for submitting and handling destructive sampling requests.

The research process and aDNA

One way to support clear communication is through an understanding of the research process. As an example, it is important for all parties to acknowledge that one of the risks of destructive sampling is that it might cause damage to the specimen but produce no informative results.

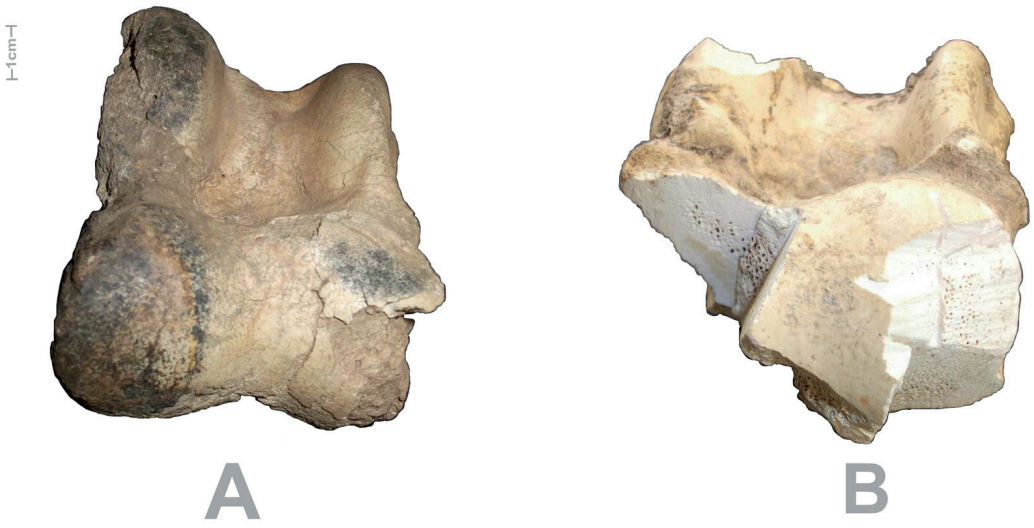

Figure 2: (A) A complete astragalus of an Aurochs, Bos primigenius (Bojanus, 1827) (PCMAG: KBC53) compared to (B) an Aurochs astragalus (PCMAG:KBC54) sampled for radio-carbon dating, both from Bob's Cave, Kitley Estate, Devon. Specimen B originally had cut marks on it showing evidence of human butchery however destructive sampling severely damaged the specimen. It was radiocarbon dated to 12,000 years old (Bailey et al., 1996). Image: Plymouth Museums, Galleries and Archives.

This is particularly pertinent for genetic analyses. DNA extracted from museum specimens is classified as ancient DNA (aDNA). aDNA research refers to the process of sampling, extracting, sequencing, and analysing the DNA from a biological, post-mortem sample, where the sample was not specifically preserved for DNA analyses. It is important to note, therefore, that the term 'ancient' does not specifically refer to the age of the DNA; the specimen can have died tens, hundreds, or hundreds of thousands of years ago. If the specimen was not immediately sampled or appropriately stored after death, the DNA will begin to fragment and decompose. This damage makes museum aDNA extremely difficult to work with, and aDNA research requires a dedicated laboratory, specialized protocols, and bioinformatics workflow. The number of bases of aDNA sequenced, for example, is typically extremely short and fragmented across the genome, and this makes them difficult to piece back together or align. In addition, post-mortem damage can alter the base sequence through deamination (the loss of an amino group), a common substitution being a cytosine (C) base erroneously read as thymine (T).

What is more, the dynamics of DNA degradation and the relationship between DNA fragmentation, time, and environment are not fully understood. Martínková and Searle (2006) explored the impact of the age of specimens and different storage conditions on the amount of genetic information obtained from museum specimens of stoats (*Mustela erminea* Linnaeus, 1758). They considered the success of DNA amplification through polymerase chain reaction (PCR) in stoats sampled across 18 museums in 11 countries. As a general rule, they found that DNA amplification was more successful in more recent specimens, and that specimens previously frozen or kept in airtight containers yielded more DNA than those kept in boxes or on shelves. However, across the 267 specimens tested, there was considerable variability. For example, some 100-year-old specimens yielded more DNA than more recent specimens did. They also noted differences in the amount of DNA obtained from skin, hair, and other tissues. A more recent study (Kistler et al., 2017) applied a meta-analysis approach, combining 185 paleogenomic datasets to compare DNA survival with sample age and environment. They found that cytosine deamination (C to T damage) increased over time, whilst the process of fragmentation increased with precipitation and temperature, but was not correlated to the age of the sample. They further suggested that tissues or microenvironments that create a closed system with reduced chemical exchange, such as in dense bone, may additionally aid the preservation of DNA in a post-mortem sample.

Another consideration is that DNA is essentially everywhere, meaning that modern DNA that is present in the environment or that has accumulated on the object, can be preferentially sequenced, rather than the very small amount of degraded aDNA present in a sample. The amount of DNA that genuinely comes from the object sampled is known as the endogenous content. Of the total DNA extracted from a sample, only a very small fraction is truly endogenous, commonly less than 1% for bone and teeth extracts (Carpenter et al., 2013). Most of this 'other' DNA will be environmental, including modern bacterial and plant DNA, but also foreign mammalian DNA including that from modern humans that have handled the sample. However, in a 'shotgun' sequencing approach, where all DNA fragments from an extract are sequenced, these contaminating sequences can be computationally removed post-sequencing.

Significantly, these aspects of aDNA research highlight that just because a researcher asks a curator to destructively sample a specimen for DNA sequencing, it doesn't mean that they will be successful or even that they will be able to do anything useful with it, with poor DNA preservation being a major limiting factor. It is important that this aspect of the research process is communicated well to the museum professional to avoid frustration over disappointing results following destructive sampling.

Minimal sampling for DNA

In the case of destructive sampling for aDNA, the conflicting interests of researcher and museum professional are lessening as sampling and sequencing technologies improve. The amount of material now required to extract and sequence DNA can be greatly reduced, from hundreds down to tens of milligrams of material. Where once whole specimens, or large parts of specimens, had to be destroyed, now most aDNA researchers can, if the sample is well preserved, extract large amounts of genetic information from material such as bone by drilling small holes to release bone powder in a process called micro-sampling. This process can use drill bits that are as small as 2-3mm in diameter, so the hole created in the sample is very small (Rowe et al., 2011).

Knowledge of the most appropriate sampling sites is also improving. A recent study by Sirak et al. (2017) reports on minimally-invasive sampling of the petrous bone in the human inner ear for DNA analyses. The petrous bone is a particularly interesting case: it represents one of the densest bones in the human body, and has recently been identified as an exceptional site for endogenous DNA preservation (Pinhasi et al., 2015). An understanding of which bones offer the best DNA preservation means researchers can now sample precious specimens more efficiently, and a welcome coincidence regarding the petrous bone is that it is well hidden from view, meaning that the external appearance of the skull remains almost entirely intact and visually undisturbed.

Over the last 30 years, improvements in sampling, laboratory methods, and DNA sequencing techniques have resulted in smaller samples being required from specimens. The average sample size needed for genetic analyses was previously in the region of 500mg (Rohland and Hofreiter 2007), but current methods mean that this can, in well-preserved material, be reduced to 50mg or less (Gansauge and Meyer 2013). The sequencing method that will be employed is a further important consideration, as methods have changed dramatically over recent years (Knapp and Hofreiter 2010). The most recent sequencing method to revolutionize the field is Next Generation Sequencing (NGS), initially described in 2005 (Margulies et al., 2005). Prior to this, most DNA sequencing would have applied polymerase chain reaction (PCR) amplification with Sanger sequencing, a targeted sequencing approach (Pääbo et al., 1989). PCR requires specific DNA fragments to be present in the sample, and for successful amplification and sequencing, the total length of those fragments must be at least 100 base pairs (bp) (Knapp and Hofreiter 2010). The NGS approach, in contrast, does not target any particular DNA fragment, as it permits all DNA fragments within the sample to be sequenced. This and other points are discussed further by Burrell et al. (2015), who specifically address the use of museum specimens in the context of advances in DNA sequencing technologies.

Micro-sampling of appropriate sites is an important development for minimising destruction to objects and maximising research output. An important point, however, is that the amount of material required is still absolute rather than proportional to the size of the specimen. A 2-3mm micro-sampling site in a mammoth tusk, for example, represents less overall damage than the same size sample from a small rodent limb bone. This has represented a problem for entomological collections, where entire specimens were often required for genetic analyses. However, improved extraction methods and Next Generation Sequencing (NGS) techniques no longer routinely require whole specimens to be destroyed. Heintzman et al. (2014), for example, successfully sequenced DNA from 134 museum beetle (Coleoptera) remains using only a single hind leg per beetle.

As well as improvements in sampling and sequencing approaches, computational tools to account for contamination and post-mortem damage in aDNA sequences are also continuing to develop. Additionally, meta-genomic approaches are becoming increasingly popular and allow for larger proportions of the raw sequence data to be evaluated. This means that DNA extracted from an object can be considered not only in terms of its endogenous content but also through evaluation of the accompanying bacterial, plant, and mammalian DNA. It is also, in most cases, a requirement for publication that researchers make DNA sequences publicly available using repositories such as GenBank (Benson et al., 2013). Some museums have also started their own DNA repositories, including the Natural History Museum of Oslo DNA Bank (Natural History Museum of Oslo, n.d.). Public repositories allow publication of a single sequence to potentially benefit a community of researchers, and also avoid the need for recurrent sampling of the same or similar specimens. For museum professionals, allowing destructive sampling of one or few specimens can thus contribute to a great volume of research. This demonstrates that what stands to be lost may be much less than what can be gained.

The DNA extracted from museum specimens can, for example, contribute significantly to our understanding of past populations and species. DNA can provide information on genetic diversity and population structure at key points in time, for example during colonisation events (Brace et al., 2015), as well as providing a genetic characterisation of species that are rare or extinct, such as the cave lion (*Panthera leo spelaea* Goldfuss, 1810) (Barnett et al., 2016). One of the most compelling examples is found in the iconic woolly mammoth (*Mammuthus primigenius* (Blumenbach, 1799)): a recent study utilised a dataset of 143 mammoth mitochondrial genomes to assess global population structure during the Late Pleistocene (Chang et al., 2017). Ancient DNA analyses have also allowed us to address our own

evolutionary past, including gene flow between anatomically modern humans and Neanderthals (*Homo neanderthanensis* King, 1864) (Kuhlwilm et al., 2016). However, it is not only DNA that can prove useful in these contexts. A novel approach to studying extinct species was taken by Welker et al. (2015), where analyses of ancient proteins were applied to resolve the evolutionary history of Darwin's South American ungulates, using collagen from museum specimens of *Toxodon* Owen, 1837 and *Macrauchenia* Owen, 1838.

A key advantage to researchers of using museum specimens is that they are often name- and date-bearing, allowing easy integration of specimens into known taxonomic frameworks. In addition, genetic data from museum specimens can be used to generate reference sequences from which further species identifications can be made, and can help to resolve taxonomic questions by placing species within phylogenies (Welker et al., 2015). Taxonomic inventories, for example, now commonly include DNA barcoding as a mechanism for identifying and characterising the diversity of a species. This facilitates rapid identification of a species, as well as allowing the opportunity for wide-scale screening of species diversity (Miller et al., 2016). Many of these inventories are also publicly accessible, a good example being the Barcode of Life Data System (http://www.boldsystems.org) (Ratnasingham and Hebert 2007). Analysis of DNA and ancient proteins can also be used to confirm when samples are closely related and, in some instances, provide information on the ancestry or geographic origins of a sample (Schroeder et al., 2015). This can facilitate research, and has the potential to add additional information to museum object displays and to communicate the research process to visitors.

As the ability to successfully sample museum specimens for research becomes easier and more cost effective, and as knowledge of specimens held in natural science collections becomes better and more openly documented, the value of natural science collections to research will continue to increase.

A changing world

Improving technology isn't just reducing the size of the sampling sites, but is also widening the possibilities with regards to which museum specimens can be successfully sampled. One example is formalin-fixed specimens, which were previously widely regarded as intractable for DNA analysis. However, in a recent study, researchers successfully extracted mitochondrial DNA from 10 snakes preserved in formalin and other fluids, using a modified DNA extraction protocol (Ruane and Austin, 2017). The specimens were up to 100 years old. Not only were the researchers able to extract sufficient genetic information to position these samples in an existing phylogeny, but this project also generated the first genetic sequence from the rare Indian snake *Xylophis stenorhynchus* (Günther, 1875).

Further examples of neglected study systems that are now being recognised as tractable include material from the tropics. Post-mortem DNA decay is highly correlated with temperature, and warm, tropical climates are known to result in increased DNA degradation (Smith et al., 2003). Research into aDNA has therefore typically focused on colder regions and samples sourced from permafrost. However, several studies in recent years have utilised tropical specimens in museum collections to look at rare and endangered Caribbean species such as the endangered Hispaniolan hutia, *Plagiodontia aedium* F. Cuvier, 1836, and the Hispaniolan solenodon, *Solenodon paradoxus* Brandt, 1833 (Brace et al., 2012; Turvey et al., 2016). Tropical specimens stored in museum collections have also been utilised to study extinct species such as the Bahamian giant tortoise (*Chelonoidis alburyorum* Franz & Franz, 2009) (Kehlmaier, 2017) and multiple species of extinct Lesser Antillean rice rats, (Cricetidae: Sigmodontinae) (Brace et al., 2015), while Schroeder et al. (2015) were able to trace the genetic ancestry of three enslaved Africans who died on the Caribbean island of Saint Martin in the late 1600s.

Previous studies have also looked at the potential to extract DNA without damaging the specimen, a process that is termed non-destructive sampling. Sampling specimens for DNA without destruction can be pertinent for small specimens such as insects, although Heintzman et al. (2014) have shown that minimally sampling beetles is a viable option. A non-destructive approach typically involves soaking all or part of the specimen in extraction buffer (Gilbert et al., 2007). This approach has been shown in PCR experiments to yield amplifiable DNA (Thomsen et al., 2009) from historic museum beetle specimens dating to 1820, and did not appear to impact on the integrity of the specimen. However, it is important to point out that the extraction efficiency is lower in non-destructive sampling, and only successful with more recent historical material (Ibid.). Assessing how

applicable this method could be with NGS techniques represents an interesting avenue for future research.

Destructive sampling procedures for museum professionals

The above examples of destructive sampling demonstrate the importance of this approach for modern research on collections. However, there is a need for greater communication between museum professionals and researchers in order to improve access to specimens and increase the understanding of the sampling required. To clarify what the researcher is asking, and for researchers to understand what the museum will allow, a 'Destructive Sampling Agreement' document and 'Destructive Sampling Request Form' should be created. Template examples are shown in Appendix 1 and 2, which have been developed by looking at examples from Leeds City Museum, Tully House Museum and Art Gallery, The Manchester Museum, the National Museum Wales, Cardiff, and the Natural History Museum. These forms can be used and adapted by readers.

The Destructive Sampling Agreement should outline the procedures for researchers, and state what information the researcher needs to submit to the museum. The agreement should state what the museum will do on receiving a request, and if the request is granted. The agreement should be clear that not all requests will be granted, and that the museum will assess each request on its own merit (see Appendix 2)

The Destructive Sampling Request Form is divided into two sections: the first section is to be completed by the researcher and sent to the museum, and the second section is to be completed by the museum professional. The first section requests details of the researcher, project, analytical laboratory, expected outcomes, and why the specimen is required. This information enables the member of museum staff to understand *exactly* what is being requested. If information is not clear, or too jargon-heavy, additional information can be requested. The second section allows the museum professional to assess the request in detail using a list of key questions. These questions are essential in not only ensuring the research proposal is understood fully, but also in assessing the risks to the collection and identifying the benefits of the research to the museum. Ultimately, the museum has the final decision on whether their specimens are used. A set of conditions to be met by the researcher is laid out at the end of Section 1 of the form. It is essential that, where a specimen is used for research that is written up in a publication, the specimen accession number and museum must be cited in the publication: this is made explicit in both the agreement and sampling form. One important condition is that the museum be acknowledged in any resultant publications, and that co-authorship is considered, based on intellectual involvement. This highlights to museum stakeholders that collections are being used in new research (Rouhan et al., 2017).

Destructive sampling best practice will involve using these forms together with a clear dialogue with researchers. Any samples taken from specimens should be extracted under the advice of the museum professional, be as minimally invasive as possible, and - where possible - in a discrete area where it will not affect any key diagnostic features of the specimen. Any unused material should be returned following sampling. It is essential to take photographs of the specimen(s) before sampling, and to attach the images to the database record. Any forms, associated documentation, or correspondence should be attached to the relevant database record and kept with the object history files. In addition, all publications resulting from research on an object should be attached to the relevant database record(s).

Conclusion

Natural science collections represent an amazing resource not only for museum staff and visitors, but also researchers. Harnessing the research potential of museum objects may require some form of destructive sampling, and this creates the need for a compromise between protecting the object and learning from the material. One common reason for requesting destructive sampling of bone and sub-fossil material is for genetic analyses, examples of which we present here. Notably, the amount of material required for aDNA research has decreased, and sequencing techniques are generating more data from a single sample. With improving techniques and a greater realisation of the importance of museum collections, the need for a successful dialogue between researchers and museum staff is becoming more important. One method for facilitating this dialogue is through the creation and implementation of appropriate destructive sampling procedures. These not only ensure that the museum can understand the research request, but also allow researchers to understand the correct museum procedures required to treat collections with appropriate care.

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Appendix I

An example of a Destructive Sampling Agreement, adapted looking at the policies from the Natural History Museum, London, National Museum Wales, The Manchester Museum, Tully House Museum and Gallery, and Leeds City Museum.

[MUSEUM NAME] Destructive Sampling Policy

One of [MUSEUM NAME]'s key missions is to enable collections to be used to enhance research. We encourage opportunities to use our collections, including destructive sampling.

Destructive sampling involves irreversible damage to an object, and, as such, decisions on sampling are taken with serious consideration.

To ensure that collections are used to their full potential, with minimal damage, the following guidelines have been laid out for researchers:

Researchers will complete the Destructive Sampling Request Form in full and send it to the curator in charge of that collection. This will include full details of the research proposal and why the specimens from [MUSEUM NAME] are required.

Researchers are encouraged to speak directly to the curator to find out more about the specimens needed for the research, i.e. suitable specimens, the best areas to sample a specimen, fragility of specimens, etc. The smallest possible sample from the least intrusive appropriate area will be taken.

Once the Destructive Sampling Request Form has been sent to the museum, the curator may ask questions to clarify information about the research project.

Where possible, and where this does not compromise the research effort, sampling should be undertaken on site under supervision and guidance of the curator and/or conservator.

If sampling is permitted, the applicant agrees to the following (which is also outlined on the Destructive Sampling Request Form):

- To provide full details of analysis techniques to the museum.
- To return all borrowed specimens and unused samples to [MUSEUM NAME] within 6 months after sampling has taken place.
- To make available all relevant results of the analysis to [MUSEUM NAME], which will be held in confidence until publication, or until a period of two years has elapsed (whichever is sooner).
- To provide a copy of all relevant publications relating to the samples listed on this form.
- To cite all specimens used in the publication with their unique museum number as supplied by the curator.
- To acknowledge [MUSEUM NAME] in any publications resulting from the sampling of the listed specimens.
- Where appropriate, to consider including the curator as a co-author on publications, if a significant intellectual contribution to a publication has been made.
- If DNA samples have been taken, to submit sequences extracted to a public repository and provide [MUSEUM NAME] with the reference numbers along with copies of sequenced data if the museum requests this. The museum will not share this data until after they have been published. Sampling muse be done in accordance with individual museum policy and in line with legal requirements and professional ethical guidelines.

Appendix 2

An example layout of a Destructive Sampling Request Form.

[MUSEUM NAME] DESTRUCTIVE SAMPLING REQUEST FORM			
Thank you for your interest in using our collections for your research. Please complete the form below with all the details of the proposed sampling and research outcomes. The curator in charge of the collection will assess the proposal and respond to you within X days. If clarification is required on any points, the curator will contact you directly.			
Section 1: To be completed by the researcher			
Name:		Position:	
Telephone:		Email:	
Address:		Date of request:	
Details of the project:			
Research outcomes (highlighting significance of destructive sampling requested):			

Analytical details:			
Type of sample required:		Amount of material required:	
Name of analyst:		Address of analytical lab:	

Sampling methods (please state the sampling methods and analysis):

Details of specimens to be sampled (please add more rows if required):			
Accession number:		Specimen name:	
Accession number:		Specimen name:	
Accession number:		Specimen name:	

If this proposal is accepted, I will:

- Return all borrowed specimens and unused samples to [MUSEUM NAME] within 6 months after sampling has taken place.
- Make available all relevant results of the analysis to [MUSEUM NAME], which will be held in confidence until publication.
- Provide a copy of all relevant publications relating to the samples listed on this form.
- Cite all specimens used in publications with their unique museum number as specified by the curator.
- Acknowledge [MUSEUM NAME] in any publications resulting from the sampling of the listed specimens.
- Where appropriate, consider including the curator as a co-author on publications, if a significant intellectual contribution to a publication has been made.
- If DNA samples have been taken, submit sequences extracted to a public repository and provide [MUSEUM NAME] with the reference numbers, along with sequenced data if requested. The museum will not share this data until after they have been published.
- Provide full details of analysis techniques to the museum.

Signed:		**Date:**	

Section 2: To be completed by museum curator		
Please assess the research proposal with the following considerations:		
About the project:	**YES**	**NO**
Is there a clear hypothesis being tested?		
Can this research be carried out without using destructive sampling on specimens?		
Could the research be done with freshly collected material?		
About the researcher:		
Does the researcher/research group have demonstrable experience of using this technique?		
Does the researcher/research group have a good record of meeting the conditions of sampling?		
About the specimen(s):		
Does the museum have full legal title to the specimen(s) requested?		
Could the method of preservation or storage of the specimen reduce the success of analysis (i.e. stored in formalin, stored in warm humid environment)?		
Has identification of the specimen(s) been independently verified?		
Is the specimen fully documented to allow any correspondence, results, etc. to be attached to records?		
Is the specimen subject to legislation that may restrict its use for the proposed work (Nagoya Protocol, CITES, etc.)?		

Proposal APPROVED / NOT APPROVED (delete as appropriate)			
Name:			
Position:			
Date:			
Specimen photographed before and after sampling (YES/NO)?		Database record updated (YES/NO)?	
Note to curator: Once completed, this form must be attached to the relevant database record and stored with the collection history files.			

Enhancing accessibility and conservation of plant tissue samples stored in silica gel, and developing a disaster plan for this collection at Royal Botanic Gardens, Kew

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Abstract

Many specimens in the Royal Botanic Gardens (RBG), Kew Plant Tissue Collection represent rare and endangered species from difficult to access regions of the world, including unique samples from a diversity of taxonomic groups. Whilst storing research materials in individual laboratories during use is accepted practice, it is unsuitable for safe long-term preservation. This paper describes the process for deposition of plant materials into the tissue collections, best practice in recuration to ensure long-term preservation and storage, and disaster planning.

Keywords: long-term storage, archival quality, biodiversity, best practice, CBD

Introduction

Botanists collect plant material e.g. for identification, genomic studies or bioprospecting of secondary metabolites. Depending on the purpose, different parts of the plant are sampled, e.g. flowers, leaves, roots, seeds, etc. For each of these parts and purposes, different protocols for field collecting exist, and are reviewed by Gemeinholzer et al. (2010). The advantages of storing plant material in silica gel for successful subsequent DNA-extractions are emphasized by Chase and Hills (1991), and this procedure has become standard in the field of Botany. Here we describe a standardized workflow for processing botanical material coming fresh from the field, to build up a plant tissue collection which can be used for both genomic and other biochemical downstream applications.

Total DNA extractions from plant tissue are still collections in the traditional sense, but require specific technologies that differ from herbarium or museum collections in many important ways. The development of best practice for what is often termed 'molecular' collections involves standardised methods for collection, long-term archival storage, retrieval and distribution. The preservation and long-term storage of material derived from biological specimens (e.g., DNA extracts) and associated data are essential to

ensure comparability and reproducibility in all areas of biological research (Corthals and DeSalle, 2005). In a centrally-managed repository, it is easier and more efficient to implement standardised procedures for modern conservation and long-term storage of silica gel dried plant tissues, and to manage access and security in a consistent and user-friendly manner, as well as adhering to the Convention of Biological Diversity (CBD). Adapting to best practice in the physical care, storage, and handling of archived material maximises life expectancy and the availability of high quality biological material for future research (ISBER, 2012). The amount of work, space, and weight needed in the field (and the herbarium), to collect and preserve suitable material for DNA studies is relatively small, given the potential benefits (Gaudeul and Rouhan, 2013).

Deposition of plant material in the tissue collections

At Royal Botanic Gardens (RBG), Kew, researchers are provided with collecting equipment and a standardised tissue sampling protocol (apps.kew.org/dnabank/SampleProtocol.pdf). As the samples collected in the field have only been preserved in a provisional way, additional handling and data management is necessary before they are deposited permanently in the research collection. In the case of plant tissue samples, permanent and safe physical space must be available and accessible. By permanent, it is understood that it will be available for storage of the collection for decades, if not centuries; by accessible, the samples can be inspected and used readily and without unnecessary delay and paperwork.

Once incorporated into a collection, voucher specimens may be examined by many researchers over time, so provision must be made for identification to be fed back to the collection and collection management system. Field identifications are not always accurate, and names can change as the understanding of particular groups develop. If the country of origin placed restrictions on the use of voucher material in the collection (or export) permit, such as stipulating that material may not be used for third-party DNA extraction, or not be sent on loan to another institution, then these restrictions need to be noted on the label of the respective specimen itself as well as in the management system of the collection housing the specimen (Savolainen et al., 2006, Gemeinholzer et al., 2010).

For final storage purposes, plant tissue dried in silica gel should be stored in archival quality resealable transparent bags bags (e.g. polyethylene zipper bags provided by Preservation Equipment Ltd.) with trace amounts of indicator silica gel (2–16 mesh, grade 42; RBG, Kew use 2-5 mm (2-5 mesh) orange-to-colourless indicating silica gel beads) in order to monitor the risk of rehydration, which can occur, for example, due to ageing containers. Ziplock bags have the advantage of being flexible, without risk of breaking (in contrast to, e.g., glass vials), inexpensive, and durable. In order to minimize exposure to air and humidity they should, in turn, be kept in tightly sealed plastic boxes (Prendini et al., 2002).

Re-curation

The re-curation process should start with plant tissue samples considered a priority e.g. current projects and type specimens. Samples are first transferred to un-buffered (archival quality) glassine envelopes with pointed forceps (or long flat forceps for large specimens in deep bags). The glassine envelope is placed in a zipped polyethylene bag. A small amount of indicating orange-to-colourless silica gel (2-16 mesh), and a label printed on acid free paper with all relevant data of the sample – as a minimum sample number, name, collector name and number (permitting auditing; see Figure 1) – should be added to the zipped polyethylene bag. The original collection bag (which might be, for example, a tea or coffee filter filled with the plant tissue sample) with the original information should be included in the outside bag as a final audit check point, but sealed separately from the sample in order to account for the risk of researchers having used non-archival materials (e.g. bags or pens) during their field work.

The recurated samples are now stored in hermetically closed containers at room temperature, ideally in a humidity-controlled environment for long-term archival storage. At RBG, Kew, we use transparent plastic containers in order to facilitate rapid checks of the humidity indicators in the silica gel without the need to open the lid of the containers. If the humidity can be maintained at a constant level rather than kept extremely low, this is adequate, but requires more frequent inspection of the collection and replacement of the indicator gel at more regular intervals (Figure 2).

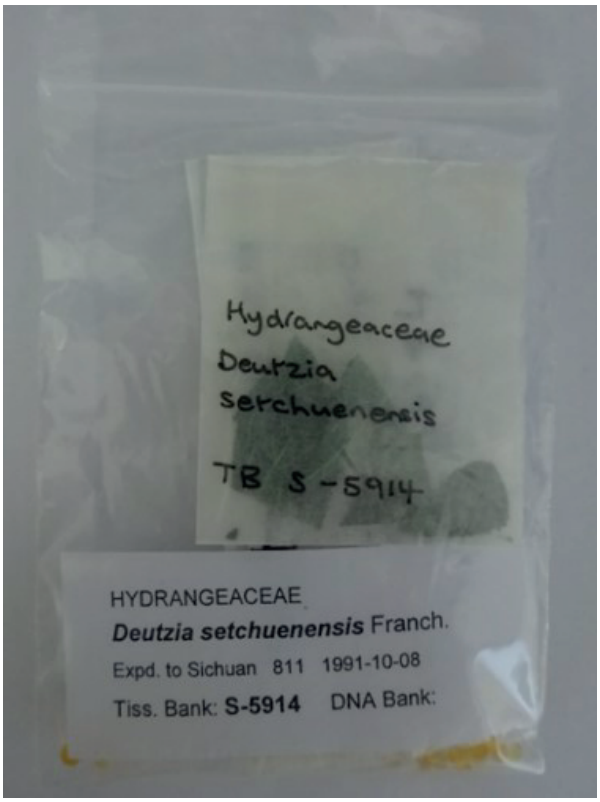

Figure 1 Recurated Sample. Image: Duque-Thüs, R., 2016.

Figure 2 Final Storage. Image: Duque-Thüs, R., 2016.

Archival quality material and storage

In the particular example of plant tissue samples stored in silica gel, there is a preference for 'preventative conservation'. This includes any action taken to prevent known damage occurring, for example by storing material in a suitable and secure environment or packing it in an appropriate way using archival quality material. 'Archival' or 'conservation' quality refers to materials that are physically durable and chemically stable. Several types of plastics and fabrics fall into this category. Such items are said to be 'inert', and do not release degradation products that can be harmful to collections. Using this type of material ensures the safety and stability of collections for long-term storage (Pasiuk, 2004).

Silica gel: health and safety

Fine crystalline silica gel allows greater surface coverage of leaf tissue, but only indurated products should be used to minimize the risk of silicosis. Crystalline silica powder or silica dust is colourless, has a higher hygroscopic capacity than silica gel, but is rarely used as it has the disadvantage of being irritating to the respiratory tract, may cause irritation of the digestive tract, and dust from the beads may irritate the skin and the eyes. Therefore, precautions for handling should be taken (Fischer Scientific, 2009). Crystalline silica dust can cause silicosis and must be used with face masks or under a laboratory hood or laminar flow cabinet (Gemeinholzer et al., 2010).

Required resources for the recuration of the tissue bank

- Pointed forceps for removing small pieces of specimen tissue from the original collection envelopes.
- Flat, long forceps for extracting large pieces of tissue from collection envelopes.
- Paintbrushes for cleaning fine silica dust from the plant tissue.
- Archival quality acid-free paper (ISO 9706) for labels.
- Unbuffered glassine envelopes (sizes S, M, and L) for storage of plant tissue.
- Zipped polyethylene bags (sizes S, M and L) for storage of glassine envelopes containing the plant tissue.
- Indicating silica gel (2-16 mesh) for monitoring of moisture levels in tissue samples.
- Transparent rectangular containers for the storage of Ziploc bags with glassine-enveloped plant tissue. For example, those containers used for professional food storage purposes from ADDIS of 4.6 litre, which are guaranteed acid-free.

Disaster plan

All disaster plans depend fundamentally on an underpinning of everyday collections management best practice and risk assessment. The first step is to identify the possible risks for the collection (Table 1).

Rescue priorities for the plant tissue collections in a disaster situation

- Type specimens.
- Unique samples e.g. extinct species or largely inaccessible (endangered species, permit problems, collecting from politically unstable countries, etc.).

Development of an emergency response team

In the event of a disaster, roles and responsibilities must be clear for everybody involved in the response. For this reason, a disaster response team must be established. It will consist of trained members of staff. Their email addresses and mobile phone numbers must be kept accessible. The team members and their roles will have to be discussed in more detail when the final storage location of the tissue sample collection is decided.

How to react after a disaster has happened?

Evacuation following a disaster must be as fast and controlled as possible. This will require appropriate modifications to existing infrastructure and equipment in the early stage of preparing the disaster plan, depending on the final location of the tissue bank.

Localisation of the samples evacuated is important. Maps with the current and suggested evacuation locations of the material have to be prepared, accessible, and shared with fire brigade officers, local fire marshals, and health and safety teams. It is essential to have the evacuated samples correctly stored in their recorded location to avoid the extra disaster that the loss of the samples would mean.

Recovery

Once a disaster has occurred, such as a broken pipe or a fire, a triage system is needed to decide which specimens are recoverable and which should be disposed of. This will be based on factors such as specimens' value and the amount of damage suffered by each specimen, for example, with the final decision on disposal to be approved by the trustees of the institution.

Table 1. Possible risks to plant tissue collections, and methods of mitigation.

Risk	Possible Consequences	Mitigation
Defective storage systems	Broken specimens. Broken containers.	Archival quality storage containers. Regular checks on specimen and container integrity.
Fire	Destruction of specimens by burning. Contamination with smoke and dust. Deterioration by water. Unknown chemical interactions between extinguishing agents and specimens or preservatives.	Following fire safety procedures. Storage of tissues in airtight and waterproof containers.
Flood	Deterioration by water.	Storage of tissues in airtight and waterproof containers. Establishment of an evacuation plan.
High air humidity	Mould growth. DNA degradation.	Monitoring of air and sample humidity. Replacing exhausted silica. Management of environmental conditions in storage area.
Heat	DNA degradation	Monitoring of temperature. Management of environmental conditions in storage area.
Pests	Destruction of specimens.	Establishment and implementation of an IPM protocol. Carrying out regular checks on specimens and containers.

Registration and evaluation of the damage

To evaluate the possible damage, it is necessary to follow an existing and established protocol (ISBER, 2012). In the case of the tissue bank there should be procedures such as:

1. Random selection and testing of a minimum of 10 samples by DNA extraction from a randomised list of samples.
2. Quality and quantity control of extracted DNA.

In May 2016, a flood occurred in the Jodrell laboratories, resulting in no losses or damage to the plant tissue collections due to best practice in storing the collection and adherence to the disaster plan previously developed (Kapinos, 2016).

Discussion

The advantages of the long-term storage of plant tissue collections are: 1) Improved access for researchers; 2) Long-time stable storage; 3) Health and safety risks of silicosis are minimised; 4) Compliance with Museum Accreditations Standards; 5) Taxonomically referenced collection available for long-term research; 6) Long-term availability of biodiversity data from the collection; 7) Possible future uses of dried whole plant tissue which can reference previous studies.

While facilitating access to samples is a key aim of the Plant Tissue Collection, RBG, Kew is committed to honouring the letter and spirit of the CBD and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and our agreements with partner countries; accordingly, some material is restricted. Kew has developed guidelines to ensure best practice for the acquisition and supply of genetic resources, based on the Principles on Access to Genetic Resources and Benefit Sharing, a document developed by 28 botanic gardens worldwide and endorsed by RBG, Kew in March 2001 (see Royal Botanic Gardens, Kew, 2004), and the Bonn Guidelines on Access to Genetic Resources and Benefit Sharing, developed under the CBD (Secretariat of the Convention on Biological Diversity, 2002). In line with the aims of the CBD, RBG, Kew's Material Supply Agreement (Royal Botanic Gardens, Kew, 2015) restricts the use of material to non-commercial use, including scientific research, education, and conservation. This encourages the recipient to share benefits fairly and equitably, and only allows for the transfer of material to a bona fide institution for non-commercial use. Likewise, all material obtained by fieldwork by RBG, Kew staff in overseas countries is bound by prior informed consent and legally mutually agreed terms.

It is important to point out that current Next Generation Sequencing techniques (High Throughput Sequencing (HTS)) can require larger quantities of material for DNA extractions; this could cause problems for botanic gardens and herbaria in the supply of plant material. For this reason, the Global Genome Biodiversity Network (GGBN, 2011; Seberg et al., 2016)) has started a public consultation on making the metadata from HTS libraries available through the data portal to help prevent HTS libraries becoming single use and to promote better use of these libraries (see GGBN, 2017).

Conclusion

Developing the long-term storage and disaster plan of the Plant Tissue Collection at RBG, Kew is an ongoing process. Additional samples stored throughout RBG, Kew are progressively being accessioned into the Tissue Collection, where they can be made available to the wider scientific community in a secure and consistent manner.

Unless there is a specific exemption, tissue collected for DNA extraction falls under CITES controls and transfer of plant tissue and DNA samples between countries are subject to CITES regulations.

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Edith Kapinos, Lucy Reed, Laszlo Csiba, co-curator of the DNA Collection from 2000 to 2015, and to the core staff of the former Molecular Systematics Section: Mark Chase, Jim Clarkson, Robyn Cowan, Dion Devey, Felix Forest. Also to the DNA and Tissue Collection volunteers Lesley Aird, Christine Bates, and Colin Dolphin.

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Taking Wing: Curating a collection of Venezuelan hawkmoths at the Manchester Museum

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Abstract

This paper reports on a project to re-curate and catalogue the Adams and Bernard collection of 174 Venezuelan hawkmoths (Lepidoptera: Sphingidae) at the Manchester Museum. The project was made possible by a grant awarded by the Natural Science Collections Association (NatSCA). The moths were set, photographed, accessioned, identified, and recorded in the museum database. The collection was found to represent 43 species in 16 genera.

Keywords: Curation, Venezuela, neotropical Sphingidae, museum collections, research, access, Heterocera, digitisation

Introduction

Manchester Museum's arthropod collections contain around 2.5 million insects, and date back to the founding of the museum in 1821 by the Manchester Society for the Promotion of Natural History (Logunov and Merriman, 2012). Logunov (2010) provides a comprehensive list of the entomology collections, but particular strengths include the worldwide collections of Coleoptera, Dermaptera, and Lepidoptera. The major collections of Lepidoptera include:

- Over 50,000 British specimens (an underestimate as not all have been counted and recorded in the museum database). The basis of the British collection is the H.N. Michaelis and R.C.R. Crewdson collections of Lepidoptera, acquired in 1959, 1962–63, and 1978 (Logunov, 2012).
- C. H. Schill's worldwide collection of 40,000 specimens, representing over 8,000 species in all families of butterflies, larger moths, and micro-Lepidoptera, donated to Manchester Museum in 1900 by the collector Charles Henry Schill (1863-). This collection also now incorporates the collections of C.O. Trechmann and A.L. Darrah (Logunov, 2010).
- The David Longsdon Papilionidae collection of 9,300 apollos, swallowtails, and birdwings, containing 87% of all described Papilionidae species. This collection was acquired by bequest of the London-based artist David Longsdon (1864–1937) in 1938 (Dockery and Logunov, 2015).
- The Paul H. Schill Palaearctic Lepidoptera collection of butterflies, larger moths, Pyralidae, Micropterigidae, Sessidae, and Psychidae, in 150 drawers (three large double cabinets and one small cabinet), acquired 1901 (University of Manchester, 1901). This collection now incorporates the L. Krah collection of European Bombycidae, Sphingidae, and Noctuidae (48 drawers), and specimens from H.G. Allcard and Joseph Sidebottom.

Figure 1. A drawer of neotropical hawkmoths (Sphinginae: Cocytiina) in the C. H. Schill collection (MANCH F4197) at Manchester Museum. Image: C. Miles.

Within the Lepidoptera collections, there are 2,010 adult hawkmoth specimens determined to species: 871 in the C. H. Schill Worldwide Lepidoptera collection (Figure 1), 768 in the British collection, and 371 in the P. Schill Palaearctic Lepidoptera collection. In total, they represent about 270 species, 19% of the world Sphingidae fauna (cf. van Nieukerken et al., 2011). In addition, there is an unquantified amount of papered material awaiting determination, from regions which include Kenya, South Africa, India, and the USA. The Adams and Bernard collection of Venezuelan Sphingidae was among this material.

The hawkmoths are a family present on every continent except Antarctica (Kitching, 2017). They have a strong forward flight, with a fast wing beat, and commonly hover like hummingbirds to feed at flowers with their long proboscis (Willmer, 2011). The hawkmoths are pollinators as adults, and some can move pollen far greater distances than, for example, bees (Willmer, 2011), having a flight capacity of over 15km (Amorim et al., 2014). Most are nocturnal, but a few are day-flying. They can be agricultural pests as leaf-feeding larvae, for example the tobacco hornworm, *Manduca sexta* (Linnaeus, 1763), the tomato hornworm, *M. quinquemaculatus* (Haworth, 1803), and the sweet potato hornworm, *Agrius cingulata* (Fabricius, 1775) (Figure 2) (Hill, 1987). Their relatively well-understood taxonomy and fast response to environmental changes makes them useful environmental indicators (de Camargo et al., 2016).

Figure 2. Agrius cingulata (Fabricius, 1775), pink-spotted hawkmoth (MANCH F2653.263) in the Adams/Bernard collection. Its larva is the sweet potato hornworm. Image: C. Miles.

The Adams and Bernard Sphingidae collection

The hawkmoths in the Adams and Bernard collection (MANCH F2653) were collected in Venezuela in May 1975. This was the third expedition to Colombia and Venezuela completed by Michael J. Adams (Figure 3), a teacher from Dorset, UK, and his friend, colleague, and fellow lepidopterist, George I. Bernard (Figure 4) (Adams, 1984; 1987). They were investigating the biogeography of the pronophiline butterflies (Nymphalidae: Satyrinae: Pronophilina) in the northern Andes, on which they published a number of papers. Altogether, Adams completed eight trips to the region between 1971 and 1986, and Bernard accompanied him on five of them (Johnson and Adams, 1993).

The information provided with the collection states that the moths were collected using the 'Mercury Vapour Lamp and White Sheet method', in which a light source with a high emittance in the ultraviolet part of the spectrum is suspended near a white surface, often a sheet hung vertically and/or placed

Figure 3. Michael Adams 'having caught a spectacular roidinid [sic]'. July 1977, Arcabuco Canyon, c.2,600m., Boyacá Department, Colombia. Riodinids are commonly known as metalmark butterflies. Image: M.J. Adams and G.I. Bernard.

Figure 4. George Bernard, March 1975, east of San Pedro de la Sierra, c.1,500m., Sierra Nevada de Santa Marta, Magdalena Department, Colombia. Image: M.J. Adams and G.I. Bernard.

flat on the ground. UV radiation attracts more moth species and higher numbers of moths than longer wavelengths, and there is some evidence these smaller wavelengths attract relatively larger moth species and a higher abundance of these species (van Langevelde et al., 2011).

The collections were made in three localities. These are, with additional detail provided more recently by Adams and Bernard (2017):

1. Rancho Grande, Henri Pittier National Park, Aragua State, at altitude 1090m (120 specimens)
2. 24 km north of Altagracia de Orituco, Guatopo National Park, Miranda State, at altitude 700m (46 specimens)
3. El Guapo Dam, Miranda State, at altitude 100m (8 specimens).

Adams' and Bernard's stay in the University facility of Rancho Grande (now Estación Biológica Rancho Grande, a high-altitude field station) and their excursion to Guatopo National Park to collect butterflies were organised by their host, Prof. Francisco Fernández Yépez, founder and curator of the Museo del Instituto de Zoología Agrícola Francisco Fernández Yépez (MIZA), Universidad Central de Venezuela, Maracay (Adams and Bernard, 2017). MIZA is dedicated to the study of tropical biodiversity and houses a nationally important hawkmoth collection (MIZA, n.d).

The hawkmoths were purchased from Adams and Bernard by Manchester Museum in April 1976 (Accession number F2653) as part of a consignment of 300 Venezuelan Heterocera (moths). The specimens were received undetermined, and have been stored in the Entomology Department in cardboard boxes, enclosed in triangular, glassine-type paper packets (Figure 5).

Figure 5. The moths as stored in glassine packets. Image: C. Miles.

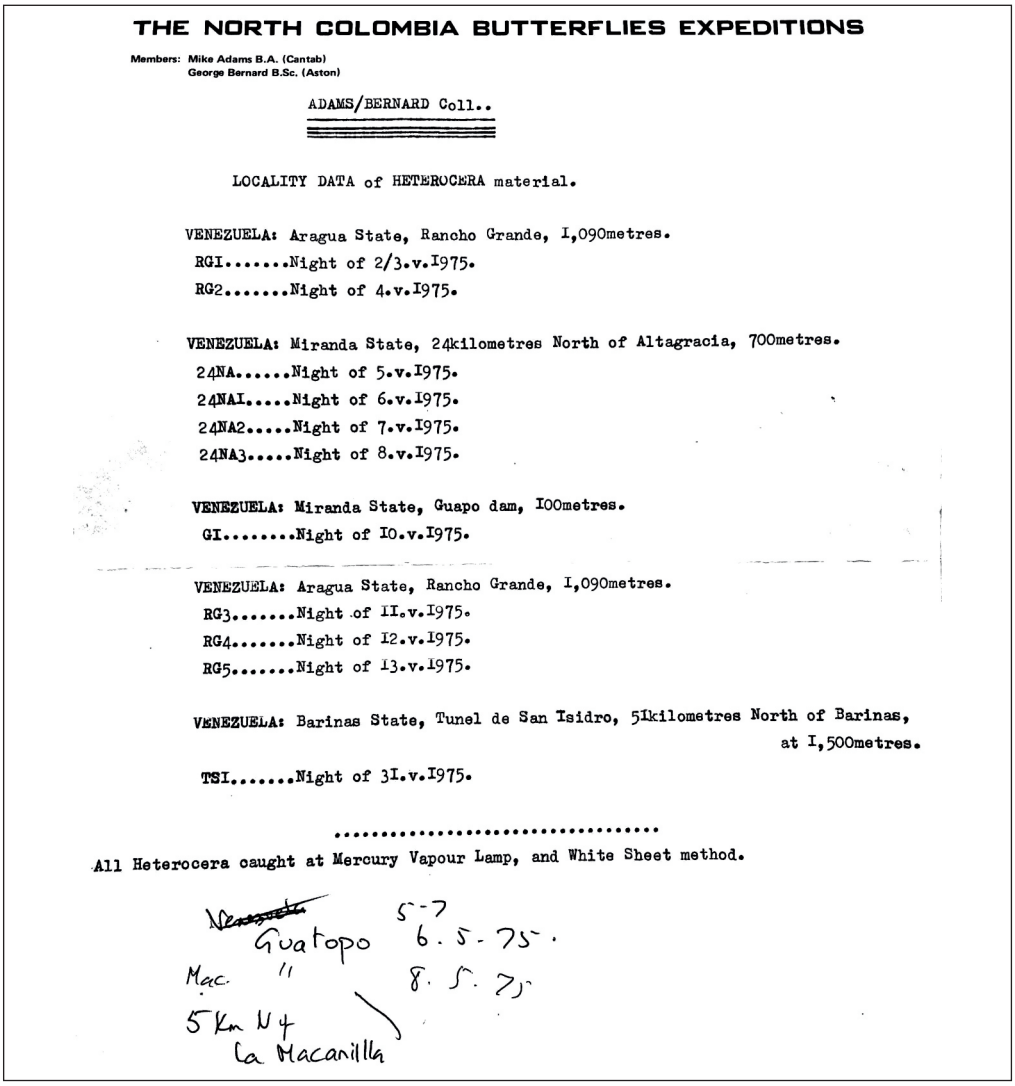
Recuration

This project was made possible thanks to a NatSCA Bill Pettitt Award grant awarded in 2016, which funded the purchase of ten glass-topped drawers with Plastazote inserts, and a reference (Kitching and Cadiou, 2000).

The aims of the project were to:

1. Improve the preservation and security of the Adams and Bernard Sphingidae collection
2. Make the collection available for study
3. Provide a resource for a range of teaching and engagement activities
4. Share and improve curatorial skills

The Adams and Bernard collection was considered suitable for this project because of its good quality associated data (Figure 6) and the generally good condition of the specimens. The moths were set (Figure 7), photographed with labels (Figure 8), individually accessioned and identified. The identification of the material was based on D'Abrera, 1986; Kitching and Cadiou, 2000; Martin, 2016; Kitching, 2017; Oehlke (n.d.), and Chacín et al. (n.d.), and the collections at Manchester Museum. Hawkmoth nomenclature and classification follows Kitching, 2017. All specimens have been recorded, with images, on the Manchester Museum's collections management database (KE EMu), making them immediately publicly accessible on the Museum's searchable external website (http://harbour.man.ac.uk/mmcustom/narratives/).



THE NORTH COLOMBIA BUTTERFLIES EXPEDITIONS

Members: Mike Adams B.A. (Cantab)
George Bernard B.Sc. (Aston)

ADAMS/BERNARD Coll..

LOCALITY DATA of HETEROCERA material.

VENEZUELA: Aragua State, Rancho Grande, 1,090metres.
RG1.....Night of 2/3.v.1975.
RG2.....Night of 4.v.1975.

VENEZUELA: Miranda State, 24kilometres North of Altagracia, 700metres.
24NA.....Night of 5.v.1975.
24NA1.....Night of 6.v.1975.
24NA2.....Night of 7.v.1975.
24NA3.....Night of 8.v.1975.

VENEZUELA: Miranda State, Guapo dam, 100metres.
G1.....Night of 10.v.1975.

VENEZUELA: Aragua State, Rancho Grande, 1,090metres.
RG3.....Night of 11.v.1975.
RG4.....Night of 12.v.1975.
RG5.....Night of 13.v.1975.

VENEZUELA: Barinas State, Tunel de San Isidro, 51kilometres North of Barinas, at 1,500metres.
TSI.....Night of 31.v.1975.

.....

All Heterocera caught at Mercury Vapour Lamp, and White Sheet method.

~~Venezuela~~ Guatopo 5-7 6.5.75.
Mac. " 8.5.75.
5 Km N of La Macanilla

Figure 6. Data provided with the collection. The handwriting is that of Manchester Museum's Keeper of Entomology at the time, Alan Brindle. Image: C. Miles.

Figure 7. Specimens spread and pinned in position with setting paper, after being relaxed in a damp atmosphere for several days. The largest moth here, Cocytius lucifer Rothschild & Jordan, 1903 (MANCH 2653.224) has a wingspan of 17 cm. Image: C. Miles.

Table 1. Sphingidae determined to species in the Adams/Bernard Collection.

Subfamily	Tribe	Subtribe	No. of genera	No. of species	No. of specimens
Macroglossinae	Dilophonotini	Dilophonotina	7	13	37
		Philampelina	2	6	18
	Macroglossini	Choerocampina	1	11	62
Smerinthinae	Ambulycini		2	3	10
Sphinginae	Sphingini	Acherontiina	1	1	2
		Cocytiina	2	3	5
		Sphingina	1	6	29
			16	**43**	**163**

Figure 8. Record shot of Hemeroplanes triptolemus (Cramer, 1779) MANCH F2653.287. Image: The Manchester Museum, The University of Manchester.

Figure 9. Species in the genus Erinnyis Hübner, [1819] from the Adams/Bernard collection in one of the new drawers. Image: C. Miles.

Results

The 174 specimens were found to represent 43 species in 16 genera, where 12 species (38 specimens) are new to the collection, an increase in Sphingidae species of 4%. In addition, for 24 of the 31 species that were not new to the collection, Venezuela extends the geographic range represented. Table 1 gives a summary of the collection. Species with their localities are listed in Appendix I.

At the time of writing, there are 11 specimens determined to genus only, pending access to comparative material: *Eumorpha* Hübner, 1807 (2 specimens), *Xylophanes* Hübner, [1819] (2 specimens), *Manduca* Hübner, 1807 (7 specimens).

Summary

With their improved physical storage (Figure 9) and security, the moths are now available for research and as a valuable resource for the museum's teaching, displays, public events and engagement activities. The hawkmoths are publicly accessible on the museum's searchable external website, and can easily be located with their associated documentation through the collections management database. The collection has already been used in research and engagement activities, which include filming of the curatorial process by students from the Granada

Centre for Visual Anthropology, and use with groups of students to illustrate the work of the museum and the use of the collections. A report describing the curatorial work in progress can be found on the Entomology Manchester blog (Miles, 2017).

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Appendix I

Table 2. Species represented in the Adams/Bernard Collection. Locality abbreviations: RG: Rancho Grande, Henri Pittier National Park, Aragua State, at altitude 1090m; NA: 24 km north of Altagracia de Orituco, Guatopo National Park, Miranda State, at altitude 700m; GD: [El] Guapo Dam, Miranda State, at altitude 100m.Taxonomy follows Kitching, 2017.

					No. of specimens			
					Locality			
Subfamily	**Tribe**	**Subtribe**	**Genus**	**Species**	**RG**	**NA**	**GD**	**Total**
Macroglossinae	Dilophonotini	Dilophonotina	*Callionima*	*falcifera* (Gehlen, 1943)	1	1		2
				parce (Fabricius, 1775)	4	1		5
			Erinnyis	*alope alope* (Drury, 1773)	8	1		9
				crameri (Schaus, 1898)	2			2
				ello ello (Linnaeus, 1758)	8		1	9
				lassauxii (Boisduval, 1859)	1			1
				oenotrus (Cramer, 1780)	1	2		3
			Hemeroplanes	*triptolemus* (Cramer, 1779)		1		1
			Madoryx	*bubastus* (Cramer, 1777)			1	1
			Pachylia	*ficus* (Linnaeus, 1758)			1	1
			Perigonia	*ilus* Boisduval, 1870	1			1
				lusca (Fabricius, 1777)	1			1
			Pseudosphinx	*tetrio* (Linnaeus, 1771)	1			1
		Philampelina	*Enyo*	*lugubris lugubris* (Linnaeus, 1771)		1		1
				ocypete (Linnaeus, 1758)			1	1
			Eumorpha	*anchemolus* (Cramer, 1779)		1		1
				satellitia licaon (Cramer, 1775)	5	5		10
				triangulum (Rothschild & Jordan, 1903)	1	1		2
				vitis vitis (Linnaeus, 1758)		2	1	3
	Macroglossini	Choerocampina	*Xylophanes*	*anubus* (Cramer, 1777)			1	1
				ceratomioides (Grote & Robinson, 1866)	9	1		10
				chiron nechus (Cramer, 1777)	3			3
				crotonis (Walker, 1856)	3			3
				germen yurakano Lichy, 1945	5			5
				neoptolemus (Cramer, 1780)	1	4		5
				pluto (Fabricius, 1777)	8	2		10
				porcus (Hübner, 1823)		1	1	2

					Number of specimens			
					Locality*			Total
Subfamily	**Tribe**	**Subtribe**	**Genus**	**Species**	**RG**	**NA**	**GD**	
Macroglossinae	Macroglossini	Choerocampina	*Xylophanes*	*pyrrhus* Rothschild & Jordan, 1906	5			5
				titana (Druce, 1878)	10	2		12
				tyndarus (Boisduval, [1875])	6			6
Smerinthinae	Ambulycini		*Adhemarius*	*gannascus* (Stoll, 1790)	8			8
				tigrina tigrina (Felder, C. & Felder, R., 1874)	1			1
			Protambulyx	*strigilis* (Linnaeus, 1771)		1		1
Sphinginae	Sphingini	Acherontiina	*Agrius*	*cingulata* (Fabricius, 1775)		2		2
		Cocytiina	*Cocytius*	*lucifer* Rothschild & Jordan, 1903	1	1		2
				antaeus (Drury, 1773)	1			1
			Neococytius	*cluentius* (Cramer, 1775)		2		2
		Sphingina	*Manduca*	*albiplaga* (Walker, 1856)	5			5
				diffissa tropicalis (Rothschild & Jordan, 1903)	4	1		5
				florestan (Stoll, 1782)	6	2		8
				lefeburii lefeburii (Guérin-Méneville, 1844)		3	1	4
				ochus (Klug, 1836)		1		1
				rustica rustica (Fabricius, 1775)	2	4		6
			Total		**112**	**43**	**8**	**163**

Surveying ultraviolet reflectance in moths: A method and workflow for data capture using open-source tools

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Abstract

Although moths are much more diverse members of the Lepidoptera compared with butterflies, there is a deficit of studies concerning their ultraviolet (UV) reflectance. The Natural History Museum, London (NHMUK), is re-curating its collection of moths occurring in the British Isles as part of the iCollections mass digitisation project. We captured UV images as an addition to the workflow. Through imaging entire drawers in UV and human-visible spectra and applying post-production methodology to standardise the images, we obtained objective and comparable UV reflectance values for 176 species in ten families, totalling 1,760 specimens. We show that usable imaging in UV above 360 nm is possible with conventional photographic equipment. UV reflectance metrics were calculated per species, and compared to usual flying time. Nocturnal species were found to reflect significantly more than diurnal.

We generated a corpus of data for UV and other morphological studies, without the need for additional expensive equipment. Scaling of the images provides for morphometric analysis. This method can be adopted as an additional module to digitisation workflows at NHMUK and other museums

Keywords: collections, digitisation, image processing, Lepidoptera, morphology, open-source software, photography, visual ecology

Introduction

The sensitivity of animals to ultraviolet (UV) light has been known since the time of Lubbock (1882), but the significance of patterns in animals has generally lagged well behind its study in plants, particularly flowers (Knuth, 1898; Chittka, et al., 1993). It was mainly pioneering studies in pierid butterflies, particularly *Gonepteryx* Leach, 1815 (Mazokhin-Porshnyakov, 1957), which highlighted its importance in animals. For example, UV reflectance has been used to resolve closely-related taxa, such as in *Gonepteryx* (Nekrutenko, 1964; Brunton, Russell and Majerus, 1996) and *Colias* Fabricius, 1807 genera (Ferris, 1973; Silberglied and Taylor, 1973; Silberglied and Taylor, 1978).

In butterflies, UV reflective patterns have also been shown to play a role in inter- and intraspecific communication: deterring predators, recognising

conspecifics, and for assessing the quality of mates (Silberglied, 1977). In *Colias eurytheme* Boisduval, 1852, male UV reflectance may be a key signal evaluated by females in assessing mate fitness, as strong reflectance is apparently due to environmental conditions in the male juvenile phase, which contribute to the production of nutritious ejaculate (Boggs and Watt, 1981).

Few studies have investigated moth UV patterns, despite many species being important pollinators and pests. A greater proportion of moths occupy these niches than butterflies within Lepidoptera, and yet butterflies have remained a main focus for UV investigations (Winfree, Bartomeus, and Cariveau, 2011). As for any other colour, interpretation of the UV reflectance as a signal depends on a complex interplay of physiological and environmental factors (Pecháček, et al., 2014). In the case of moths, such factors are, for example, their visual systems and anti-predator strategies, physical properties of reflected light (Johnsen, et al., 2006), the moths' flying and resting postures (Dennis and Shreeve, 1989; Briscoe, et al., 2003), and predator attack techniques (Olofsson, et al., 2013). Night vision also has low signal-to-noise ratios, and factors such as the speed of motion, direction of the stimulus, and chromatic and achromatic contrast are of great relevance (Cronin, et al., 2014; Zapletalová, et al., 2016).

The ongoing iCollections digitisation project (Paterson, et al., 2016) at the Natural History Museum, London (NHMUK) presented an opportunity to study UV reflectance. This project (in which authors EC and SL were involved) is digitising approximately one million specimens in the collection of British and Irish Lepidoptera. During digitisation, spatial, temporal, and other data is captured at specimen level, providing the data keys which permit the development of a UV survey via digital photography. Recent advances in photography have overcome lighting and sensor variations (Stevens, et al., 2007), preventing artefacts that impede analysis. Sensor arrays provide information about entire areas more quickly than extensive point-sampling with spectrometers (Cuthill, et al., 1999; Endler and Mielke, 2005). Calibration techniques, as well as colourspace conversions to specific animal visual systems, are becoming easily available (Troscianko and Stevens, 2015). To use existing resources, we chose to acquire UV reflectance by photographing entire drawers at the time of digitisation – hence we sampled only species from the British and Irish fauna using a non-specialist but high-resolution camera. Even though such equipment is specifically designed to reduce UV sensitivity, it is our main purpose to show that useful results are still achievable.

Method

The moths examined are pinned specimens of the British and Irish collection of NHMUK, digitised by the iCollections project, with 176 species available at the time: in the Drepanidae Boisduval, 1828, Lasiocampidae Harris, 1841, Endromidae Boisduval, 1828, Saturniidae Boisduval, 1837, Sphingidae Latreille, 1802, Geometridae Leach, 1815, Notodontidae Stephens, 1829, Erebidae Leach, 1815, Noctuidae Latreille 1809 and Nolidae Bruand, 1846. Each drawer holds between 30 and 600 specimens, mounted with their wings open, normally showing the dorsal side; information labels and a Data Matrix barcode are pinned underneath. The drawers were placed next to a scale bar and colour chart and

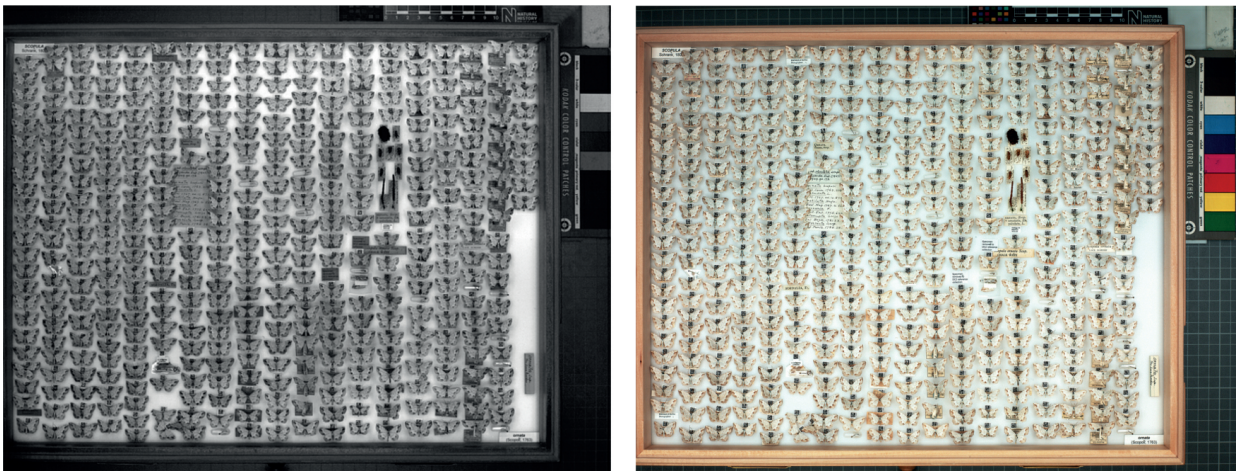

Figure 1: Drawer 70-021-1 (Scopula ornata) showing scales and colour chart in UV (left) and visible (right). Image: NHMUK, 2016.

imaged in batches, refocusing when the illumination was changed (Figure 1). Where a single species filled several drawers in the collection, we imaged only the first one.

Equipment

All the images were taken through Capture One software by a Phase One iXR camera fitted with a Mamiya LS 80mm *f*/2.8 D lens and a Phase One Credo 80 digital back, which has a Teledyne DALSA sensor (53.7 x 40.3 mm) with 5.2 x 5.2 µm pixels. UV images were taken at 50 ISO, *f*/12, 30 sec., and those in visible light at 50 ISO, *f*/12, ¼ sec. UV images were taken through a B+W 403 UV-pass filter.

The UV lighting consisted of four 18-inch T8 25 W fluorescent blacklight tubes with peak at 368 nm (Sylvania Black Light 368), arranged rectangularly. The visible illumination was a HerbScan lightbox (HerbScan Engineering) of 300 LEDs (HIDS4U, cool white, 60 LEDs per metre, nominally 72 W at 62.5 lm W^{-1}, before a white acrylic diffuser). The UV lighting was fitted inside the visible lighting system, and both lit the drawer evenly from directly above.

The overall system spectrum peaks at 375 nm and spans 361-392 nm (10%), with smaller 'leakage' spikes at 405 and 435 nm (Figure 2).

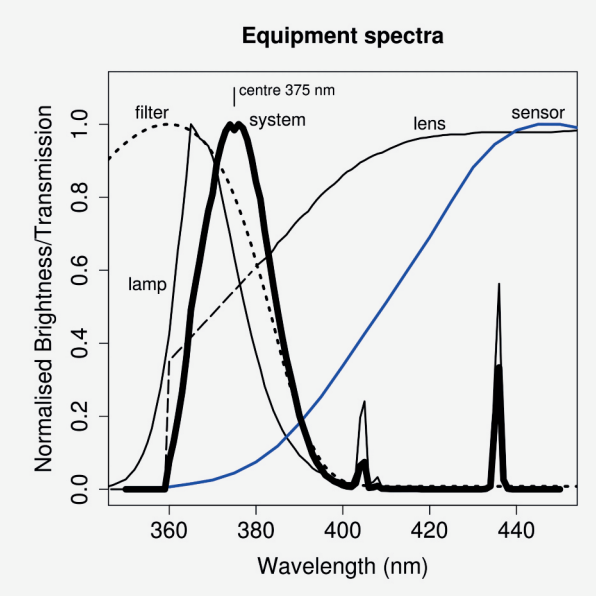

Figure 2. Spectra for lamp emission, filter and lens transmission, and sensor sensitivity, from their respective manufacturers' data. Lens transmission for 360-380 nm is an estimate, extrapolated from the 380-400 nm segment. The thick black line represents the calculated overall estimated system spectrum for the UVA-blue region.

Control images were taken to ensure we captured UV wavelengths: a) samples of aluminium (kitchen foil, polished side), which reflects both visible and UV light (Coblentz and Stair, 1929), and zinc oxide (dental grade powder), which reflects visible light and absorbs UV (Rodnyi and Khodyuk, 2011) (Figure 3); and b) two male specimens of the butterfly *Gonepteryx rhamni rhamni* (Linnaeus, 1758), for visual proof-of-concept comparison with existing studies (Pecháček, *et al.*, 2014) (Figure 4). We also imaged a standard Stemmer A3 test chart.

Image and metadata capture

We used web forms to capture the drawer identification and illumination type, matching these to the captured images through the image and form submission time stamps. This avoided the need to use expensive proprietary software, and made the capture process streamlined.

All the images were captured in the camera's proprietary lossless raw format 'IIQ Large' with accompanying XML metadata ('COS') file. We converted these to an appropriate lossless PNG format for maximum portability, subsequently processing with standard tools (Imagemagick `convert`) and a small number of custom functions, detailed below. Data is kept in an SQL database (MariaDB).

Scaling and noise reduction

The visible light images were converted into linear 16-bit PNG format (`dcraw -4`), and we manually marked a number of control positions: the inside corners of the drawer, and the colour chart registration marks. The white balance was set from the colour chart with matrix colour transformation (`convert -recolor`).

The portion of the image inside the drawer (471 x 361 mm) was then transformed by perspective correction into an image of 9600 x 7360 pixels (`convert -perspective`). Allowing for vertical variation in the positioning of the specimen, this gives a linear scale of 0.05 mm $pixel^{-1}$ ±2%.

The UV images required special treatment. The sensor used, as in most colour digital cameras, has a Bayer filter over a panchromatic sensor. Our images were taken under very low light conditions, and showed considerable salt and pepper noise, defined as highly deviant single pixel bright and dark values on the underlying sensor, normally spread over multiple

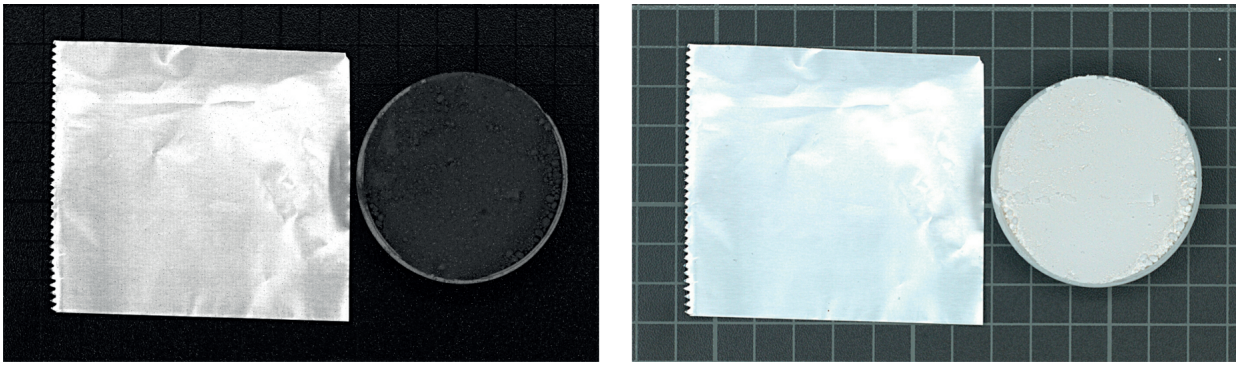

Figure 3: Control images of the aluminium foil (square) and zinc oxide (round) under UV (left) and visible (right) illumination. Note that the zinc oxide is dark under UV and white under visible light. Image: NHMUK, 2016.

Figure 4: Control images of male Gonepteryx rhamni rhamni under UV (left) and visible light (right). Note the bright UV patches on the forewings, corresponding to Pecháček, et al. (2014). Image: NHMUK, 2016.

pixels during demosaicing, and only the blue-filter pixels provided useful results under UV illumination. Our principal reflectance measurement was quantile-based; it was unaffected by pepper noise, which was therefore ignored. The raw IIQ files were converted to linear 16-bit PNG files without any colour interpolation (`dcraw -D`), and the blue-filter pixels extracted to give a half-width, half-height image, corrected for noise (custom programs `debayer` and `denoise`). This latter is a simple decision-based median filter (Astola and Kuosmanen, 1997), where each pixel is replaced by the median of its eight neighbours if its value exceeds the largest neighbour by *p* standard deviations of the neighbours, or an absolute *q;* this second condition being required for many very dark regions where the neighbour pixels have identical value. We used $p = 1.5$ and $q = 5.0$, which identified 1.9% of the pixels as salt noise. Figure 5 shows a portion of the aluminium control image, where the three shaded pixels were replaced by the median of their neighbours. Finally, images were level-converted to give densities of 20% and 80% to the black and white patches of the colour chart, and scaled to 4800 x 3680 pixels, giving a scale of 0.1 mm pixel^{-1} ±2%.

Specimen extraction and processing

For each drawer, we generated ten coordinates at random and manually selected the nearest specimens which had a) unobscured barcodes, b) were not artificially bred, and c) were not visibly damaged. As the specimens are densely positioned in columns and are of the same species, bias towards larger specimens was considered negligible. Their barcodes were read (79% with dmtxread, remainder manual) and stored.

Attempts to use computer vision (OpenCV) for image segmentation were unsuccessful because: a) the specimens often overlapped a barcode, labels, or other specimen, b) lighting artefacts obscured specimen edges, and c) the background polyethylene foam material (Plastazote) is UV-reflecting. We therefore created mask files manually by drawing outlines over multilayer SVG files (Inkscape), allocated at random to several technicians who were instructed

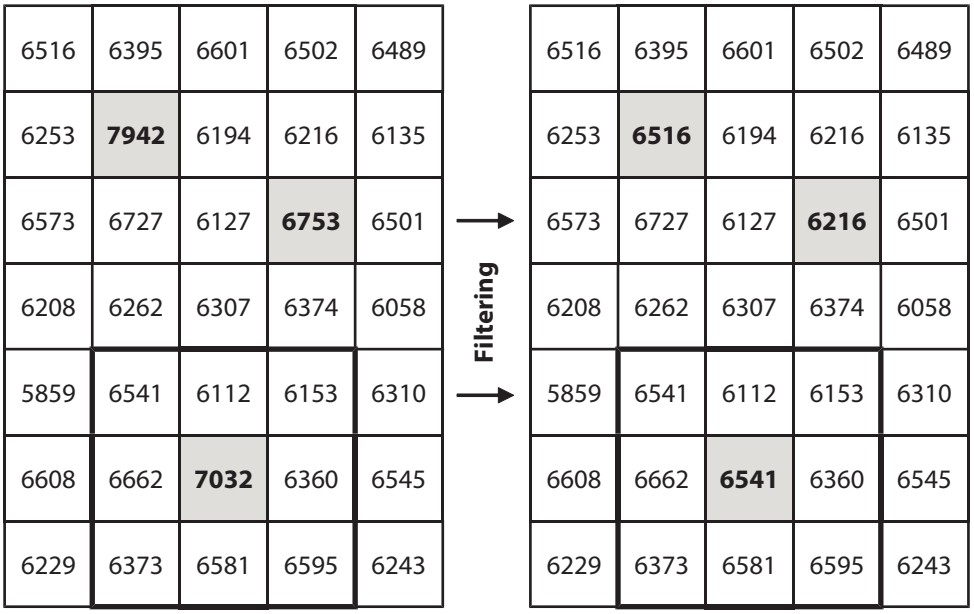

*Figure 5: Salt noise filtering detail with values from centre of aluminium sample, as 16-bit integers, before (left) and after (right) filtering. A decision-based median filter was used to reduce this noise: shaded values are much brighter than their eight neighbours, and thus considered as noise and replaced: eg pixel value 7032 > max(neighbours)+sd(neighbours)*1.5, so it is replaced by the higher of the central two values (as proxy for median) of the neighbours, 6541.*

to err on the side of omitting portions of the specimen. This process was the most time-consuming, with an average of 10.4 minutes per specimen, in contrast to 16 minutes per drawer for imaging.

Specimen pixels were normalised to floating point in (0, 1) for statistical processing in R, producing values for each specimen: mean, standard deviation, and each centile. In order to disregard patterning, we wished to allocate the same reflectance value to species which have highly-reflective patches as those with high reflectivity overall. We therefore chose the 75th percentile brightness value as our principal metric of reflectance, *R*. The value for a species is simply the mean of the values for the specimens.

Results

Survey

This dataset comprises species belonging to ten families with varying species richness (Table 1). The reflectance quantified with this method is summarised in Table 2 (see Appendix I). Three species of varying reflectance are shown in Figure 6. The brightest species are *Euproctis similis* (Fuessly, 1775), *Scopula ornata* (Scopoli, 1763), *Jodis lactearia* (Linnaeus, 1758), *Euproctis chrysorrhoea* (Linnaeus, 1758), *Leucoma salicis* (Linnaeus, 1758), *Idaea subsericeata* (Haworth, 1809), *Utetheisa pulchella* (Linnaeus, 1758), *Cilix glaucata* (Scopoli, 1763), *Lithostege griseata* (Denis & Schiffmüller, 1775), *Nola aerugula* (Hübner, 1793), and *Cosmorhoe ocellata (Linnaeus, 1758)*. These are strictly nocturnal species, with the exception of *U. pulchella,* which is both diurnal and nocturnal. Five of these top reflective species belong to the Geometridae and four to the Erebidae, both nocturnal pollinators (Winfree, Bartomeus and Cariveau, 2011; LeCroy, Shew and VanZandt, 2013). The other two known nocturnal pollinator families, Noctuidae and Sphingidae (Winfree, et al., 2011; LeCroy, et al., 2013) were amongst the lowest reflectance, but were also poorly represented in this dataset: *Diloba caeruleocephala* (Linnaeus, 1758) was the only species representing Noctuidae and only five species represented Sphingidae of the 18 species present in UK. Moreover, one of these five species, *Hemaris fuciformis* (Linnaeus, 1758), has partially transparent wings and *Macroglossum stellatarum* (Linnaeus, 1758) is a diurnal species.

UV reflectance and activity time

We compared the relationship between UV reflectance and usual flying time of the species (Figure 7). We excluded those species where females and males differ in the time of daily activity or where one

Table 1: The families and numbers of species in the survey (total is as given as present in the British Isles in Agassiz et al., 2013).

Family	Surveyed	Total	Coverage (%)
Drepanidae	11	16	68.8
Lasiocampidae	6	12	50.0
Endromidae	1	1	100.0
Saturniidae	1	1	100.0
Sphingidae	5	18	27.8
Geometridae	109	307	35.5
Notodontidae	13	29	44.8
Erebidae	20	88	22.7
Noctuidae	1	368	0.30
Nolidae	9	12	75.0

Figure 6: Images in visible light and UV respectively of Euproctis similis, BMNH(E)1561127, 1a and b, Habrosyne pyritoides (Hufnagel, 1766), BMNH(E)1537703, 2a and b, and Saturnia pavonia (Linnaeus, 1758), BMNH(E)1530710, 3a and b, selected as most, medium and low UV reflectant species. Images: NHMUK, 2016.

or both sexes fly both in day and night time (Townsend and Waring, 2011; Newland et al., 2013; UKMoths, n.d.), species for which activity time could not be found, and subspecies. We see that in our sample, the strictly nocturnal species are more reflective of UV, and also much more numerous (n = 126) than the strictly diurnal (n = 10).

An independent samples Welch's t-test was performed, to compare the UV reflectance value of diurnal and nocturnal species. There was a significant difference in the reflectance of diurnal species (m = 0.255, sd = 0.066) and nocturnal species (m = 0.381, sd = 0.113); $t(13.7) = -5.45$, $p<0.001$, which is significant at the 0.1% level.

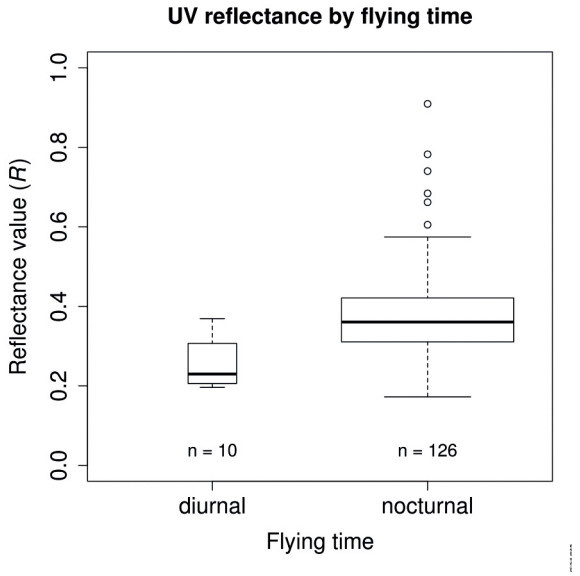

Figure 7: UV reflectance by flying time of strictly diurnal and strictly nocturnal species.

Discussion

The methodology presented in this paper resulted in two major outputs: the survey of a phenotypical character (UV reflectance) in a group of invertebrates (Lepidoptera) where its taxonomic distribution has been largely unknown, and the establishment of a workflow for exploiting digitised collections for the purposes of large-scale morphological surveys.

The quantification of reflectances presented in Table 2 (see Appendix I) adds to knowledge of wing reflectance in these species, which is potentially useful for morphologically-based systematics and for behavioural studies.

Specimen barcodes can be used to link the UV reflectivity of individual specimens to spatial, temporal and other collecting information captured during digitisation at NHMUK. This information will allow correlations between reflectance and possible distribution patterns across the UK, such as perhaps latitude, or, as in Brooks, et al. (2016), correlation with meteorological data for monitoring phenological changes of butterflies. Reflectance gradients could correspond geographically to abiotic factors, such as the amount of UV radiation reaching the land surface at given times of year (Herman, et al., 1999).

We found that, in the species we surveyed, UV reflectance is generally higher in nocturnal than diurnal species, which is consistent with a study of Finnish moths (Lyytinen, et al., 2004).

Detailed interpretation of these values is beyond the scope of the current survey, and needs to take into account many factors involved in intra- and interspecific communication. We nevertheless attempt to provide a basic context to some of the results.

Interspecific communication

The portion of the UV spectrum we studied corresponds in general to the visual range of passerine birds (Cuthill, et al., 2000; Lind, et al., 2014), which are expected to predate diurnal and crepuscular moths. Notably, in our dataset, the exclusively-diurnal species (10 geometrid species plus the sphingid *Macroglossum stellatum*) have similar levels of reflectance, significantly lower than nocturnal species. In human vision, these diurnal species have very dull colours that are presumably useful as camouflage to a range of vertebrates.
It is difficult to speculate on the role of UV reflectance as a defence mechanism in nocturnal moths, as few potential nocturnal predators are known to have night vision. Rodents are apparently the only nocturnal group with UV vision (Jacobs, et al., 1991), with bats relying on echolocation and birds of prey on acoustic cues at night (Honkavaara, et al., 2002). UV perception is not necessarily concomitant with colour vision: some owls and bats (Winter et al., 2003) apparently perceive UV achromatically in low light (Parejo, et al., 2010). The nightjar *Caprimulgus europaeus* Linnaeus, 1758 may use the same mechanism in deep crepuscular and nocturnal hunting of moths (Sierro, et al., 2001).

Intraspecific signals

Signalling using markings only differentiated in UV has been demonstrated in *Heliconius* Kluk, 1780 butterflies (Bybee, et al., 2011), and perhaps this is the case for *D. elpenor* (Linnaeus, 1758) (Figure 8). This species shows UV-reflective patches corresponding to only some of its pink markings. It has UV-blue-green trichromatic vision (Schwemer and Paulsen, 1973; Kelber, et al., 2002; Kelber and Roth, 2006), with peaks at 345 nm, 440 nm, and 520 nm (Hamdorf, et al., 1971; Schlecht, 1979; Schwemer and Paulsen, 1973). Johnsen, et al. (2006) show that longer wavelengths

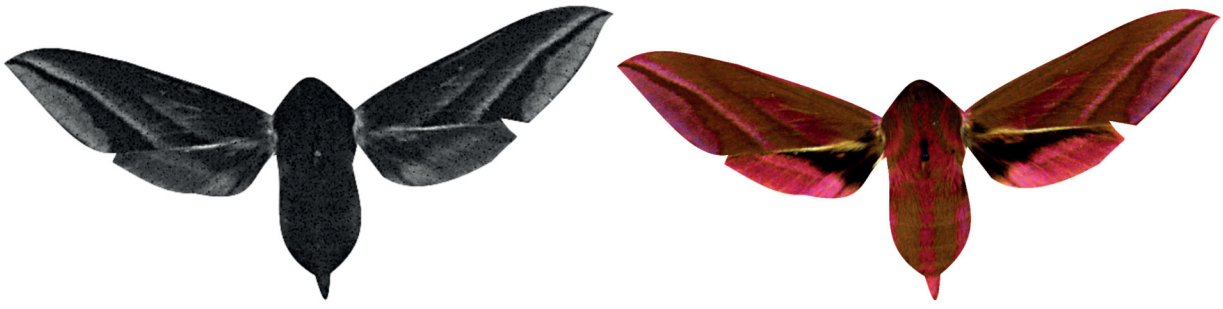

Figure 8: Deilephila elpenor, specimen BMNH(E)1640207, showing UV reflectance (left) corresponding to pink portions of the wing (right) but not body stripes. Images: NHMUK, 2016.

become relatively more visible during moonlight and starlight.

The 12 dimorphic species surveyed, six of which are apterous, reflected a moderate to low amount of UV, and did not show any significant correlation relating the reflectance either with the sex, nor the fact that they are wingless.

Many of the species surveyed here exhibited a moderately low UV reflectance, which nonetheless may play a considerable role. It is known that some moths can be very sensitive to small UV signals, as some species are lured to the webs of orb spiders which have minute UV-reflective spots (Chuang, et al., 2008; Blamires, et al., 2012).

We observed apparent differences in UV reflectance in the green colouration in Geometridae versus Nolidae. The pigmentary green of the geometrid subgroup emeralds (Cook, et al., 1994) is known to fade after emergence in three of the five species we examined (*Pseudoterpna pruinata atropunctaria*, *Jodis lactearia,* and *Hemithea aestivaria)* but not *Geometra papilionaria* or *Comibaena bajularia*, and in fact, after many years, colour is still vivid in the specimens of the latter. All these five species have moderately high UV reflectance, and *J. lactearia* was the third most reflective species in the entire dataset. In the Nolidae, we surveyed three green species: *Earias chlorana*, *Bena bicolorana* and *Pseudoips prasinana britannica*. Remarkably little is known about the green colouration in this family, but it seems to be produced by pigments, as in the case of the Emeralds, but of different chemical composition (Ford, 1972), and fading is unreported. In this survey, nolids reflected considerably less UV than the emeralds.

If the individuals in these species can distinguish UV, blue, and green, as shown in other moths (Briscoe and Chittka, 2001), being UV- and/or green-reflective might function as an intraspecific signal. Furthermore, considering that *J. lactearia* is even more UV-reflective after losing its green colouration, the green pigments may actually mask some physically UV-reflective structure, and the fact that these species lose the colour at different rates may even mediate different interspecific signalling.

Light directionality is a potential concern, because it is known that the structural colour which generates the UV reflectance can be angle-dependent (Nekrutenko, 1964; Ghiradella, et al., 1972; Kemp, 2006). Specimens have uncontrolled orientation: we note in this respect the review of Kemp and Rutowski (2011), in which they described the presentation of iridescent patterns on the nymphalid and pierid male butterfly dorsal surface "*via highly ritualised aerial courtship routines*", with orientation clearly significant for signalling.

Considerations for assessing UV reflectance in museum collections

To qualify our results, it is important to understand some characteristics of the underlying collection. The British and Irish Lepidoptera collection at NHMUK originates from an amalgamation of donated collections of both wild-trapped and captive-bred moths and butterflies, collected between approximately the 1880s and 1970s. Some of the captive-bred specimens in particular were labelled as aberrations, a rank of no current taxonomic standing used by collectors attempting to describe polymorphism (Salmon, et al., 2000). These were often the result of experiments and so not relevant for systematic and ecological studies. There is also some bias towards rare forms in the wild-trapped specimens, and collecting methods and sampling effort vary substantially between collectors, some being caught using UV light traps, whilst others were netted or, more recently, attracted with pheromones. Brooks, et al. (2016) found that in the butterfly species of this collection, there is a geographical bias towards the South East of England: the same is not yet reported for the moth collection, but may well exist. A final point regarding colouration is variation in killing and preserving chemicals, some of which are known to alter pigment colours (Martin, 1977). In the case of UV reflectance, which is structurally produced, we might be concerned with naphthalene, which is UV-absorbing, and paradichlorobenzene, which is reported to re-crystallise on specimen wings when used in excess (Martin, 1977).

Conclusions

Museum collections and digital photography offer the opportunity to survey morphology rapidly and on a large scale. Our survey concentrates on a feature that is intrinsically difficult to detect and to interpret in its ecological role. Standardisation of images nowadays confers a great degree of freedom in capturing and analysing colour traits. UV reflectance has been generally neglected because of these difficulties, despite being, in nature, just another colour and significant to many animals and plants. We hope that this survey will support future work on validation of species reflectance, live observation of UV display, and

also encourage museums to investigate this trait in their collections and link it to geographical, temporal, and ecological factors.

Acknowledgements

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Data accessibility

Image data, database tables, scripts and program source code are available through NHMUK entry DOI: 10.5519/0019732.

Equipment suppliers

Mamiya Leaf: Mamiya Phase One iXR camera
http://www.mamiyaleaf.com/ixr.html

with Schneider Kreuznach 80 mm LS f2.8 lens
http://www.mamiyaleaf.com/lenses.html
https://captureintegration.com/schneider-ls-lens-mtf-charts-for-phase-one-mamiya/

and Credo 80 back
http://www.mamiyaleaf.com/credo.html

Teledyne DALSA sensor: spectra as given in the datasheets for the slightly smaller FTF9168C
https://www.teledynedalsa.com/public/sensors/datasheets/FTF9168C_datasheet_20130530.pdf

Schneider: B+W 403 filter
http://www.schneiderkreuznach.com/fileadmin/user_upload/bu_photo_imaging/fotofilter/Produktfinder/Infos/B_W_Filter_Info_Transmission_403_UV-Pass.pdf

Sylvania: F25W 18-in. T8 BL368 Toughcoat UV-A lamps
Blacklight brochure 2013. Havells Sylvania Belgium B.V.B.A.

HerbScan lightbox
25 Fairway, Chertsey, KT16 8EB, herbscan@mac.com

Stemmer Imaging: test chart
http://www.stemmer-imaging.co.uk/en/knowledge-base/test-chart

Kodak Color Control Patches
http://motion.kodak.com/IN/en/motion/Products/Lab_And_Post_Production/Control_Tools/KODAK_Color_Separation_Guides_and_Gray_Scales/default.htm

Software

Phase One: Proprietary RAW format
http://help.phaseone.com/en/CO7/Output/File-formats/Capture-One-and-RAW.aspx

DCRAW: image conversion software version 9.26
http://www.cybercom.net/~dcoffin/dcraw

DMTXREAD: Datamatrix barcode decoder version 0.7.4 (with libdmtx version 0.7.4)
http://libdmtx.sourceforge.net

Imagemagick: conversion software version 6.7.7-10
http://www.imagemagick.org

Inkscape: vector drawing package version 0.91
http://www.inkscape.org

MariaDB: server version 10.0.17, client version 5.5.46
https://mariadb.org

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Appendix I

Table 2: UV reflectance by species and grouped by family, the brightest ten species in bold: species names are as printed in the drawers. ***Drawer*** *gives NHMUK drawer number;* ***n****, number of specimens examined;* ***R****, UV reflectance values;* ***Night*** *and* ***Day****, time of day activity specified by sex;* ***Notes: d****=dimorphic and* ***a****=apterous (Townsend and Waring, 2011; Newland et al., 2013; UKMoths, n.d.). Dimorphic species are reported separately for each sex with the exception of Pseudoips prasinana britannica (Warren, 1913) which is dimorphic, but the sexes were indistinguishable in our specimens.*

Taxon	Drawer	n	R	Night	Day	Note
Drepanidae						
Watsonalla cultraria (Fabricius, 1775)	65-003/1	10	0.28	mf	m	
Drepana falcataria (Linnaeus, 1758)	65-005/1	10	0.29	mf		
Sabra harpagula (Esper, 1786)	65-006/1	10	0.29	mf		
Cilix glaucata (Scopoli, 1763)	65-007/1	10	**0.56**	mf		
Thyatira batis (Linnaeus, 1758)	65-008/1	10	0.38	mf		
Habrosyne pyritoides (Hufnagel, 1766)	65-009/1	10	0.35	mf		
Tethea ocularis octogesimea (Hübner, 1786)	65-010/1	10	0.32	mf		
Tetheella fluctuosa (Hübner, [1803])	65-012/1	10	0.45	mf		
Ochropacha duplaris (Linnaeus, 1761)	65-013/1	10	0.35	mf		
Cymatophorina diluta hartwiegi (Reisser, 1927)	65-014/1	10	0.41	mf		
Polyploca ridens (Fabricius, 1787)	65-015/1	10	0.38	mf		
Lasiocampidae						
Trichiura crataegi (Linnaeus, 1758)	66-002/1	10	0.35	mf		
Eriogaster lanestris (Linnaeus, 1758)	66-005/1	10	0.32	mf	m	
Lasiocampa trifolii flava Chalmers-Hunt, 1962	66-006/1	10	0.28			
Lasiocampa quercus quercus (Linnaeus, 1758)	66-007/1	10	0.22			
Macrothylacia rubi (Linnaeus, 1758) m	66-008/1	2	0.21	m	m	d
Macrothylacia rubi (Linnaeus, 1758) f	66-008/1	8	0.29	f		d
Euthrix potatoria (Linnaeus, 1758) m	66-010/1	6	0.24	m		d
Euthrix potatoria (Linnaeus, 1758) f	66-010/1	4	0.26	f		d
Endromidae						
Endromis versicolora (Linnaeus, 1758) m	67-001/1	5	0.22	m	m	d
Endromis versicolora (Linnaeus, 1758) f	67-001/1	5	0.32	f		d
Saturniidae						
Saturnia pavonia (Linnaeus, 1758) m	68-001/1	4	0.21		m	d
Saturnia pavonia (Linnaeus, 1758) f	68-001/1	6	0.25	f		d
Sphingidae						
Mimas tiliae (Linnaeus, 1758)	69-001/1	10	0.22	mf		
Hemaris fuciformis (Linnaeus, 1758)	69-009/1	10	0.32		mf	
Macroglossum stellatarum (Linnaeus, 1758)	69-010/1	10	0.23		mf	
Deilephila elpenor (Linnaeus, 1758)	69-016/1	10	0.25	mf		
Deilephila porcellus (Linnaeus, 1758)	69-017/1	10	0.21	mf		
Geometridae						
Idaea muricata (Hufnagel, 1767)	70-002/1	10	0.32	mf		
Idaea fuscovenosa (Goeze, 1781)	70-006/1	10	**0.51**	mf		
Idaea subsericeata (Haworth, 1809)	70-009/1	10	**0.59**	mf		
Idaea aversata (Linnaeus, 1758)	70-016/1	10	0.29	mf		
Scopula ornata (Scopoli, 1763)	70-021/1	10	**0.79**	mf		
Scopula rubiginata (Hufnagel, 1767)	70-022/1	10	0.24	mf		
Scopula imitaria (Hübner, [1799])	70-024/1	10	0.33	mf		
Timandra comae Schmidt, 1931	70-029/1	10	0.36	mf		
Cyclophora pendularia (Clerck, 1759)	70-030/1	10	0.35	mf		
Cyclophora annularia (Fabricius, 1775)	70-031/1	10	0.39	mf		
Cyclophora albipunctata (Hufnagel, 1767)	70-032/1	10	0.39	mf		
Cyclophora puppillaria (Hübner, [1799])	70-033/1	10	0.26	mf		
Cyclophora punctaria (Linnaeus, 1758)	70-036/1	10	0.3	mf		

Taxon	Drawer	n	R	Night	Day	Note
Cyclophora linearia (Hübner, [1799])	70-037/1	10	0.3	mf		
Rhodometra sacraria (Linnaeus, 1767)	70-038/1	10	0.39	mf		
Scotopteryx luridata plumbaria (Fabricius, 1775)	70-041/1	10	0.38	mf		
Xanthorhoe decoloraria decoloraria (Esper, [1806])	70-048/1	10	0.37	mf		
Xanthorhoe decoloraria hethlandica (Prout, 1901)	70-048/2	10	0.3	mf		
Xanthorhoe fluctuata fluctuata (Linnaeus, 1758)	70-049/1	10	0.41			
Xanthorhoe spadicearia ([Denis & Schiffermüller], 1775)	70-051/1	10	0.29	mf		
Xanthorhoe quadrifasiata (Clerck, 1759)	70-055/1	10	0.26	mf		
Catarhoe cuculata (Hufnagel, 1767)	70-056/1	10	0.41	mf		
Epirrhoe tristata (Linnaeus, 1758)	70-060/1	10	0.36		mf	
Euphyia biangulata (Haworth, 1809)	70-064/1	10	0.38	mf		
Mesoleuca albicillata (Linnaeus, 1758)	70-068/1	10	**0.53**	mf		
Entephria flavicinctata ruficinctata (Guenée, 1858)	70-071/1	10	0.41	mf		
Entephria caesiata ([Denis & Schiffermüller], 1775)	70-072/1	10	0.41	mf		
Entephria caesiata hethlandicaria (Bang-Haas, 1910)	70-072/2	10	0.37			
Entephria caesiata caesiata ([Denis & Schiffermüller], 1775)	70-072/3	10	0.42			
Hydriomena impluviata ([Denis & Schiffermüller], 1775)	70-075/1	10	0.31	mf		
Thera obeliscata (Hübner, [1787])	70-081/1	10	0.34	mf		
Cidaria fulvata (Forster, 1771)	70-085/1	10	0.39	mf		
Cosmorhoe ocellata (Linnaeus, 1758)	70-087/1	10	**0.54**	mf		
Eustroma reticulata ([Denis & Schiffermüller], 1775)	70-088/1	10	0.36	mf		
Eulithis prunata (Linnaeus, 1758)	70-089/1	10	0.37	mf		
Eulithis testata (Linnaeus, 1761)	70-090/1	10	0.35	mf		
Eulithis populata (Linnaeus, 1758)	70-091/1	10	0.33	mf		
Eulithis mellinata (Fabricius, 1787)	70-092/1	10	0.45	mf		
Ecliptopera silaceata ([Denis & Schiffermüller], 1775)	70-094/1	10	0.37	mf		
Dysstroma citrata citrata (Linnaeus, 1761)	70-098/1	10	0.38			
Colostygia pectinataria (Knoch, 1781)	70-100/1	10	0.41	mf		
Operophtera fagata (Scharfenberg, 1805) m	70-105/1	5	0.48	m		da
Operophtera fagata (Scharfenberg, 1805) f	70-105/1	5	0.3			da
Operophtera brumata (Linnaeus, 1758) m	70-106/1	5	0.39	m		da
Operophtera brumata (Linnaeus, 1758) f	70-106/1	5	0.25			da
Epirrita dilutata ([Denis & Schiffermüller], 1775)	70-107/1	10	0.46	mf		
Epirrita autumnata (Borkhausen, 1794)	70-109/1	10	0.46	mf		
Hydrelia flammeolaria (Hufnagel, 1767)	70-114/1	10	0.34	mf		
Rheumaptera hastata hastata (Linnaeus, 1758)	70-120/1	10	0.27		mf	
Hydria undulata (Linnaeus, 1758)	70-121/1	10	0.33	mf		
Hydria cervinalis (Scopoli, 1763)	70-122/1	10	0.28	mf		
Horisme vitalbata ([Denis & Schiffermüller], 1775)	70-126/1	10	0.34	mf		
Odezia atrata (Linnaeus, 1758)	70-130/1	10	0.2		mf	
Perizoma affinitata (Stephens, 1831)	70-132/1	10	0.36	mf		
Perizoma alchemillata (Linnaeus, 1758)	70-133/1	10	0.4	mf		
Gagitodes sagittata (Fabricius, 1787)	70-140/1	10	0.37	mf		
Chloroclystis v-ata (Haworth, 1809)	70-142/1	10	0.37	mf		
Eupithecia linariata ([Denis & Schiffermüller], 1775)	70-150/1	10	0.32	mf		
Eupithecia venosata venosata (Fabricius, 1787)	70-155/1	10	0.39	mf		
Eupithecia tripunctaria Herrich-Schäffer, 1852	70-160/1	10	0.32	mf		
Eupithecia insigniata (Hübner, 1790)	70-174/1	10	0.34	mf		
Eupithecia extensaria occidua Prout, 1914	70-178/1	10	0.45	mf		
Eupithecia expallidata Doubleday, 1856	70-180/1	10	0.34	mf		
Eupithecia vulgata (Haworth, 1809)	70-183/1	10	0.32	mf		
Eupithecia succenturiata (Linnaeus, 1758)	70-188/1	10	0.38	mf		
Eupithecia subumbrata ([Denis & Schiffermüller], 1775)	70-189/1	10	0.46	mf		

Taxon	Drawer	n	R	Night	Day	Note
Carsia sororiata anglica Prout, 1937	70-191/1	10	0.37	mf		
Aplocera plagiata plagiata (Linnaeus, 1758)	70-192/1	10	0.45	mf		
Aplocera efformata (Guenée, [1858])	70-193/1	10	0.42	mf		
Chesias legatella ([Denis & Schiffermüller], 1775)	70-195/1	10	0.39	mf		
Chesias rufata rufata (Fabricius, 1775)	70-196/1	10	0.35	mf		
Lithostege griseata ([Denis & Schiffermüller], 1775)	70-197/1	10	**0.54**	mf		
Lobophora halterata (Hufnagel, 1767)	70-198/1	10	0.48	mf		
Acasis viretata (Hübner, [1799])	70-200/1	10	0.36	mf		
Archiearis parthenias (Linnaeus, 1761)	70-203/1	10	0.2		mf	
Boudinotiana notha (Hübner, [1803])	70-204/1	10	0.23		mf	
Abraxas grossulariata (Linnaeus, 1758)	70-205/1	10	0.3	mf		
Abraxas sylvata (Scopoli, 1763)	70-206/1	10	0.43	mf		
Ligdia adustata ([Denis & Schiffermüller], 1775)	70-208/1	10	0.41	mf		
Macaria notata (Linnaeus, 1758)	70-211/1	10	0.34	mf		
Macaria carbonaria (Clerck, 1759)	70-216/1	10	0.26		mf	
Chiasmia clathrata clathrata (Linnaeus, 1758)	70-218/1	10	0.25	mf	mf	
Isturgia limbaria (Fabricius, 1775)	70-220/1	10	0.2		mf	
Cepphis advenaria (Hübner, 1790)	70-221/1	10	0.37		mf	
Petrophora chlorosata (Scopoli, 1763)	70-222/1	10	0.45	mf		
Plagodis pulveraria (Linnaeus, 1758)	70-223/1	10	0.25	mf		
Plagodis dolabraria (Linnaeus, 1767)	70-224/1	10	0.3	mf		
Opisthograptis luteolata (Linnaeus, 1758)	70-226/1	10	0.24	mf		
Epione vespertaria (Linnaeus, 1767) m	70-228/1	10	0.25	m	m	d
Pseudopanthera macularia (Linnaeus, 1758)	70-229/1	10	0.19		mf	
Angerona prunaria (Linnaeus, 1758)	70-230/1	10	0.16	mf		
Apeira syringaria (Linnaeus, 1758)	70-231/1	10	0.22	mf		
Ennomos quercinaria (Hufnagel, 1767)	70-233/1	10	0.32	mf		
Ennomos alniaria (Linnaeus, 1758)	70-234/1	10	0.25	mf		
Ennomos erosaria ([Denis & Schiffermüller], 1775)	70-236/1	10	0.25	mf		
Selenia dentaria (Fabricius, 1775)	70-237/1	10	0.31	mf		
Selenia lunularia (Hübner, [1788])	70-238/1	10	0.26	mf		
Selenia tetralunaria (Hufnagel, 1767)	70-239/1	10	0.3	mf		
Odontopera bidentata (Clerck, 1759)	70-240/1	10	0.3	mf		
Crocallis elinguaria (Linnaeus, 1758)	70-241/1	10	0.31	mf		
Ourapteryx sambucaria (Linnaeus, 1758)	70-243/1	10	0.32	mf		
Colotois pennaria (Linnaeus, 1761)	70-244/1	10	0.37	mf		
Alsophila aescularia ([Denis & Schiffermüller], 1775) m	70-245/1	7	0.43	m		da
Alsophila aescularia ([Denis & Schiffermüller], 1775) f	70-245/1	3	0.25			da
Apocheima hispidaria ([Denis & Schiffermüller], 1775) m	70-246/1	7	0.33	m		da
Apocheima hispidaria ([Denis & Schiffermüller], 1775) f	70-246/1	3	0.22			da
Lycia hirtaria (Clerck, 1759)	70-248/1	10	0.3	m		
Biston betularia (Linnaeus, 1758)	70-252/1	10	0.38	mf		
Pseudoterpna pruinata atropunctaria (Walker, 1863)	70-297/1	10	0.37	mf		
Geometra papilionaria (Linnaeus, 1758)	70-299/1	10	0.41	mf		
Comibaena bajularia ([Denis & Schiffermüller], 1775)	70-300/1	10	0.35	mf		
Jodis lactearia (Linnaeus, 1758)	70-303/1	10	**0.72**	mf		
Hemithea aestivaria (Hübner, 1789)	70-305/1	10	0.39	mf		
Notodontidae						
Cerura vinula (Linnaeus, 1758)	71-003/1	10	0.44	mf		
Furcula furcula (Clerck, 1759)	71-005/1	10	0.49	mf		
Furcula bifida (Brahm, 1787)	71-007/1	10	0.47	mf		
Stauropus fagi (Linnaeus, 1758)	71-009/1	10	0.3	mf		
Drymonia dodonaea ([Denis & Schiffermüller], 1775)	71-010/1	10	0.37	mf		

Taxon	Drawer	n	R	Night	Day	Note
Drymonia ruficornis (Hufnagel, 1766)	71-011/1	10	0.39	mf		
Pheosia tremula (Clerck, 1759)	71-017/1	10	0.42	mf		
Pterostoma palpina (Clerck, 1759)	71-020/1	10	0.32	mf		
Ptilodon capucina (Linnaeus, 1758)	71-021/1	10	0.3	mf		
Ptilodon cucullina ([Denis & Schiffermüller], 1775)	71-022/1	10	0.31	mf		
Phalera bucephala (Linnaeus, 1758)	71-025/1	10	0.38	mf		
Clostera curtula (Linnaeus, 1758)	71-027/1	10	0.33	mf		
Clostera pigra (Hufnagel, 1766)	71-028/1	10	0.26	mf		
Erebidae						
Leucoma salicis (Linnaeus, 1758)	72-009/1	10	**0.65**	mf		
Lymantria monacha (Linnaeus, 1758)	72-010/1	10	0.43	m		
Lymantria dispar (Linnaeus, 1758) m	72-011/1	4	0.26	m	m	d
Lymantria dispar (Linnaeus, 1758) f	72-011/1	6	0.47			d
Euproctis chrysorrhoea (Linnaeus, 1758)	72-012/1	10	**0.67**	mf		
Euproctis similis (Fuessly, 1775)	72-013/1	10	**0.89**	mf		
Orgyia antiqua (Linnaeus, 1758) m	72-017/1	5	0.21	m	m	da
Orgyia antiqua (Linnaeus, 1758) f	72-017/1	5	0.23			da
Orgyia recens (Hübner, [1819]) m	72-018/1	7	0.19	m		da
Orgyia recens (Hübner, [1819]) f	72-018/1	3	0.19	f		da
Coscinia cribraria bivittata (South, 1900)	72-032/1	10	0.37	mf		
Utetheisa pulchella (Linnaeus, 1758)	72-034/1	10	**0.58**	mf	mf	
Miltochrista miniata (Forster, 1771)	72-035/1	10	0.39	mf		
Cybosia mesomella (Linnaeus, 1758)	72-038/1	10	0.46	mf		
Pelosia muscerda (Hufnagel, 1766)	72-039/1	10	0.38	mf		
Lithosia quadra (Linnaeus, 1758) m	72-041/1	6	0.41	m		d
Lithosia quadra (Linnaeus, 1758) f	72-041/1	4	0.33	f		d
Atolmis rubricollis (Linnaeus, 1758)	72-042/1	10	0.22	mf	mf	
Eilema depressa (Esper, 1787)	72-043/1	10	0.35	mf		
Eilema griseola (Hübner, [1803])	72-044/1	10	0.42	mf		
Eilema lurideola (Zincken, 1817)	72-045/1	10	0.44	mf		
Eilema pygmaeola pygmaeola (Doubleday, 1847)	72-048/1	10	0.41	mf		
Eilema sororcula (Hufnagel, 1766)	72-049/1	10	0.34	mf		
Setina irrorella (Linnaeus, 1758)	72-050/1	10	0.4	mf	m	
Noctuidae						
Diloba caeruleocephala (Linnaeus, 1758)	73-033/1	10	0.31	mf		
Nolidae						
Meganola strigula ([Denis & Schiffermüller], 1775)	74-001/1	10	0.39	mf		
Meganola albula ([Denis & Schiffermüller], 1775)	74-002/1	10	**0.52**	mf		
Nola cucullatella (Linnaeus, 1758)	74-003/1	10	0.38	mf		
Nola confusalis (Herrich-Schäffer, 1847)	74-004/1	10	0.47	mf		
Nola aerugula (Hübner, 1793)	74-005/1	10	**0.54**	mf		
Bena bicolorana (Fuessly, 1775)	74-007/1	10	**0.52**	mf		
Pseudoips prasinana britannica (Warren, 1913)	74-008/1	10	0.38	mf		d
Nycteola revayana (Scopoli, 1772)	74-009/1	10	0.33	mf		
Earias clorana (Linnaeus, 1761)	74-011/1	10	0.47	mf		
Controls						
Gonepteryx rhamni rhamni (Linnaeus, 1758)	N/A	2	0.38			
Aluminium	N/A	1	1			
Zinc Oxide	N/A	1	0.41			

Using web-based tools to transform the Bivalvia collection database in the KwaZulu-Natal Museum

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Abstract

The initial steps towards digitising the KwaZulu-Natal Museum's Mollusca collection were taken in 1994. This involved the creation of a Microsoft Access database with a relatively small number of fields designed to capture the essential details of specimen provenance. South Africa has funded national institutions to create metadata which will lead to digitisation (including databasing, digital imaging, and georeferencing), by promoting and increasing access to natural history collection data to a much broader user base. However, at KwaZulu-Natal Museum, the initial progress was very slow, due to problems with database design and lack of expertise. In 2014, a pilot project was initiated to use GEOLocate Web Application to georeference collection records of the Bivalvia database which already have locality descriptions but lack geographic information. Subsequently, the digitised Bivalvia data have been supplied to help big science projects in South Africa. It is anticipated that the records will ultimately be linked to other databases, and used to update coordinates to these other datasets.

Keywords: biodiversity data, digitisation, georeferencing, natural science collections

Introduction

The two research departments of the KwaZulu-Natal Museum (Human Sciences and Natural Sciences) have received funds from the National Research Fund (NRF) to digitise all of their collections. The Natural Science Digitisation Project (NSDP) was developed as part of this national initiative with the aim to digitise, standardise, and clean all of its collection databases. This initiative follows the model of The Global Plants Initiative (GPI) project, which has increased plant collector research and the compilation of such data (Penn et al, 2018). This initiative aims to help national institutions to create metadata which will lead to digitisation (including databasing, digital imaging, and georeferencing), by promoting and increasing access to natural history collection data to a much broader user base (Berent et al, 2010). The objectives are thus to digitise and mobilise biodiversity data stored in museums, herbaria, and research institutions in South Africa towards creating one research infrastructure. To achieve this, it was noted that the digitised data include species name, georeferenced location, collector and collection date, and other specimen data recorded on the label by the collector (Paterson *et al.,* 2016).

The collections management system SPECIFY was adopted by this national initiative as standard for all animal specimens, to ensure sustainable preservation of the collections and that data meet the Darwin Core Standards. However, because of limited 'in-house'

human capacity, NSDP has targeted the training of interns and volunteers to perform some tasks, although the inevitable turnover presents set-backs. Because of the size of some of the collections, migration to SPECIFY might take a long time and thus compromise other 'in-house' research priorities. In addition to this, the cost of extracting data from open-sources has not yet been evaluated by the KwaZulu-Natal Museum curators who have, to date, used the data in its current format in Microsoft Access, and are happy with that format. Because of this, it has been difficult to measure the success of capacity-building training, due to lack of application of these tools. Certain tools, however, such as georeferencing, have been adding value to the collections.

The first practical phase of the digitisation project was in the year 2014-2015. Georeferencing tools were used to add geographic coordinates into the Bivalvia database, and promising results were achieved through a short staff training programme. Digitising the Bivalvia database was a pilot project because this database was incomplete; many of its records were not yet databased and of those that were, many records lacked geographic coordinates. The aim of this work was to use the GEOLocate Web Application (Rios and Bart, n.d.) to georeference collection records of the Bivalvia database of the KwaZulu-Natal Museum that already had locality descriptions but lacked geographic information. It is believed that, once complete, this exercise will provide guidelines for cleaning and improving the quality of data for end-users, thus saving time and money in repeating similar tasks with other databases at KwaZulu-Natal Museum and other South African institutions in general.

Mollusca Collection

The mollusc collection consists predominantly of dry shells, but, where possible, wet samples of each species are preserved in ethanol for anatomical examination. The Mollusca collection has benefited greatly from the shell collection and library of Henry Cliften Burnup (1852 - 1928), who was Honorary Curator of Mollusca. After his death in 1928, his collection was incorporated into the Mollusca collection and significant expansion occurred through field work, donation, and exchange, as well as purchase (Kilburn and Herbert, 1994). Fieldwork is usually conducted on an annual basis in order to build up the collection, as well as to improve the taxonomic and ecological data associated with specimens. One of the biggest programmes was the Natal Museum Dredging Programme (NMDP), which began in 1981 and continued until 1997, on annual 10 days cruises (Kilburn and Herbert, 1994). 1,100 stations were sampled, ranging between off KwaZulu-Natal to south-western Cape, as well as on the Agulhas Bank (Kilburn and Herbert, 1994). This programme enriched the KwaZulu-Natal Museum mollusc collection with the most extensive and accurately documented samples. These samples include many rare and unusual species such as *Nassarius eusulcatus* (G.B. Sowerby III, 1902), *Anadara africana* (G.B. Sowerby III, 1904) (now a synonym of *Anadara pygmaea* (H. Adams, 1872)), *Anatoma yaroni* Herbert, 1986, and *Puncturella voraginosa* Herbert & Kilburn, 1986, to mention very few (Kilburn and Herbert, 1994). The Mollusca collection ranks among the 15 largest in the world, and is certainly the largest in both Africa and the Indian Ocean rim. Currently, this collection houses more than 160,000 specimens, many of which have been fully databased in MS Access.

Mollusca databasing

The initial steps toward digitising the museum's Mollusca collection were taken in 1994. This involved the creation of an MS Access database with a relatively small number of fields, designed to capture the essential details of specimen provenance. Initial progress was very slow, due to problems with database design and lack of staff expertise. In 1996, Ntombi Mkhize was employed on a part-time basis and she began to input data for the non-marine component of the collection. In 1999-2000, additional funding was accessed through SA-ISIS/BioMAP (South African Integrated Spatial Information System / Biodiversity Mapping and Assessment Programme), initiated by the Department of Arts and Culture, and Science & Technology. This allowed the employment of a dedicated databasing technician for circa two years, before the funding ceased. Subsequently, at its own expense, the museum employed Ntombi Mkhize again on a full-time basis to continue the Mollusca databasing work. After her resignation in 2014, there was a brief hiatus until Matabaro Ziganira was appointed and, finally, the databasing backlog was eliminated in 2016.

The databasing of the collection was initiated primarily as a research tool, facilitating rapid access to distribution and inventory data, and to make spatial data available to potential stakeholders who might require such information (e.g. KZN Wildlife). For this reason, data entry was initially restricted to records

from southern Africa and the south-western Indian Ocean. Only when this was completed, was databasing expanded to include our holdings from other parts of the world, by which time, the specter of GRAP 103 compliance was also looming large. GRAP 103 is an accounting standard that prescribes the uniform accounting for classifying and recording Heritage Assets, and regulates related disclosure requirements. The standard requires that institutions have records of their collections that are fit-for-purpose, and which contain basic information about objects, including: identification, ownership, location, condition, and value. Public Entities reporting to the Department of Arts and Culture must comply with the requirements set out in the standard. On its own, GRAP 103 has no scientific value. Only when the goals of potential stakeholders such as the South African Biodiversity Institute (SANBI) are brought in, does the exercise become one of scientific value.

The Bivalvia database

The Bivalvia database was created in early 2000 using MS Access, a commonly-known and widely utilised programme for museum collection management. This database contains 25,000 records, many of which are old specimens, collected many years ago. All the information stored in this database is organised in a spreadsheet containing only available and pertinent data for the collected specimens (eg. taxonomic determination, locality description, collection date, etc.) (see Table 1 in Appendix I). The locality information primarily describes the place where specimen data were recorded at the time of collection. However, some of these records lack geographic locations, or the locality description might be ambiguous or inaccurate, or simply not correspond to current geographic location due to anthropological changes (Chapman, 2005; Chapman and Wieczorek, 2006). This limitation makes it difficult to validate the coordinates, and errors are usually difficult to detect. In addition, the extent to which validation can occur depends on how well the locality information describes the same place (Chapman and Wieczorek, 2006). Thus, the process of georeferencing the Bivalvia database also aimed at cleaning the data, and normalising/harmonising ambiguous records to unambiguous master records, through selection and import of unique records only into the GEOLocate Web Application (http://www.museum.tulane.edu). However, there were instances where records did not provide coordinates because of ambiguous or erroneous locality descriptions. In such cases, the 'County' column in the spreadsheet was labelled 'not georef' to indicate that no coordinates were available (see Table 2 in Appendix I). Another conflict occurred when coordinates were misplaced to a different location, or simply presented a very high degree of uncertainty on the map. To resolve this, the knowledge of the Chief Curator, Professor Herbert, was essential. Usually, the Chief Curator knew either the collector's collection events, or was aware of the geo-political changes in the country of collection. Also, the Chief Curator understood the interpretation of the symbols used on the specimen records, and was able to clarify the queries. Paterson et al (2016) state that in resolving erroneous and misleading label information, such as collecting localities and dates, the knowledge of the curator is crucial; the curator might know about the collector in question, or might have collected other specimens from the same locality, or at the same time. Good records information, such as locality descriptions, can lead to more accurate georeferences with smaller uncertainty values, and thus provide users with much more accurate and higher-quality data (Chapman and Wieczorek, 2006).

Data export to Microsoft Excel

The Bivalvia database was exported into a Microsoft Excel spreadsheet, retaining complete formatting and layout (Figure 1). In the MS Excel datasheet, columns (ID and ID1) were added on each side of the spreadsheet, containing the same sequential numbers in exact order. Adding these numbers minimises the chance of errors caused by mixing up records while filtering and sorting many rows in the Excel datasheet. It is highly recommended that the entire process of georeferencing follows guidelines that are designed to reduce errors and repeatability (Paterson et al, 2016). A copy of the sorted datasheet was made, in which subsequent queries were made. In the copied sheet, the 'locality' column was filtered by selecting 'unique record only', and a new copy of the datasheet was made. After filtering, 5,000 records were found to have unique localities, and these were used for the georeferencing exercise. The remaining 20,000 records were considered 'excluded records', because they had duplicate locality descriptions which were already represented in the 5,000 unique records. This is very important because in some instances, many specimens are collected in the same locality with similar descriptions. In those cases, it is imperative that 'unique locality only' are georeferenced in a batch mode. In this way, one needs only deal with a single record out of many with similar locality descriptions in the database, therefore saving

invaluable time. After the georeferencing process was completed, the georeferenced spreadsheet was exported back into the original database in MS Access format, and, through a series of queries, the georeferencing information from the 5,000 'unique records' was added to the corresponding 20,000 'excluded records' in the database.

Georeferencing of the Bivalvia database

Georeferencing of the Bivalvia database was primarily done through locality descriptions. The 5,000 unique records were sorted electronically and formatted in a CSV file before upload to the GEOLocate Web Application (http://www.museum.tulane.edu) (see Table 3 in Appendix I). GEOLocate is a platform for georeferencing natural history collection data, and is currently being developed as a web service through integration and development of BioGeomancer (BioGeomancer Working Group, 2005) (Figure 2). Tools such as BioGeomancer work better when georeferencing is done in batch mode. The locality description is submitted and the georeference reports back by providing further information on uncertainty, where several options exist from the locality information (Chapman and Wieczorek, 2006). After data were georeferenced and while the database was still online, I evaluated each record individually by marking the non-georeferenced records for further review, and also assessed and validated each record for uncertainty error (Figure 3).

In most instances where geographic information was given, uncertainty data were usually attached for each record georeferenced.

Locality descriptions of many records of the Bivalvia database are based on named places that might have changed in size over time. In some instance, this phenomenon renders the current extent of a named place greater than its historical range (Chapman and Wieczorek, 2006). For this reason, GEOLocate uses an uncertainty polygon by clipping a circle where it overlaps the ocean for terrestrial data, and thereby providing a much more accurate representation of the locality (Chapman and Wieczorek, 2006). This allowed me to either agree or modify the extents that might not reflect the uncertainty predictions from the several options that GEOLocate suggested. In order to accurately georeference the Bivalvia database, the knowledge of the Chief Curator and Google Earth were constantly referred to for verification of the current locality information during data sorting and validation (Figure 3).

Importing and merging of georeferenced data into the main database

Once the process of evaluation and assessment was completed, the next step was to import the georeferenced database back into the main database. This was executed by importing and converting the georeferenced CSV file into MS Access format and

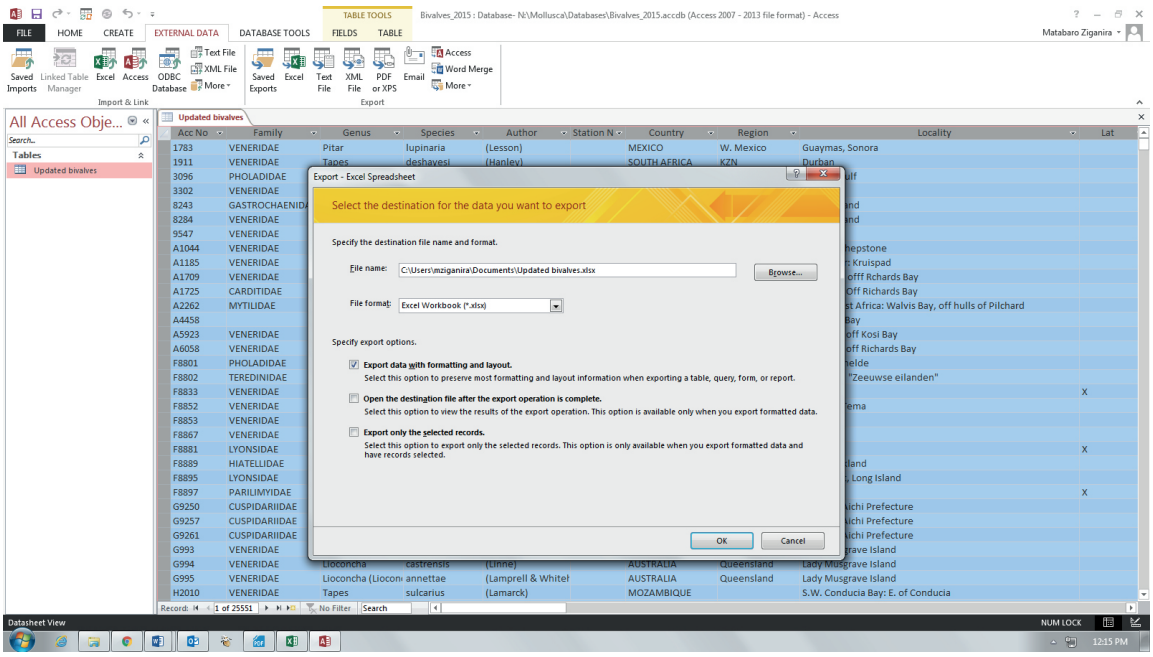

Figure 1. The import process of the Bivalvia database into Microsoft Excel spreadsheet from Microsoft Access.

merging the two spreadsheets as one database. It was expected that the 5,000 unique georeferenced records would influence the 20,000 non-georeferenced records in the main database by adding geographic information to records with similar locality descriptions. However, if the merging is not properly executed, errors and confusion might negatively affect the main database. In order to prevent errors during this process, two new columns were inserted into the georeferenced database, namely 'ID1' and 'locality backup'. The 'ID1' column had ascending numeric values of one to 5,000 and was inserted as column number one of the spreadsheet. The 'locality backup' was a duplicate of the locality column that was used during georeferencing, and was placed next to the 'ID' column as the last column of the spreadsheet. This strategy is imperative because it exposes errors where numeric values do not correspond to the associated locality description after the merging of the two spreadsheets. A copy of this database was made for reference. In the original database, fields entitled 'georeference comments', 'correction status', 'precision', 'error polygon', 'multi results', 'radius uncertainty', 'radius uncertainty1', 'radius uncertainty2', and 'locality fixed' were inserted in this table. Through creating and executing queries in MS Access, the information in the georeferenced database was combined with the original database. Columns labelled 'latDD' and 'longDD' in the two databases were interconnected based on the similarity of their locality descriptions. This allowed the georeferenced record to directly add geographic information to records in the main database with similar locality descriptions. This means that small numbers of unique records are able to influence the entire dataset, thus saving valuable time and money.

The geographic information derived from the process of georeferencing is usually in the format of degrees decimal. Some of the 20,000 'excluded records' in the main database had already been allocated geographic information in the format of degrees, minutes, and seconds. Because of the format differences, it was important that the 'excluded records' be converted into degrees decimal format so that consistency was maintained in the database. To do this, a new MS Excel spreadsheet was created from the 'excluded

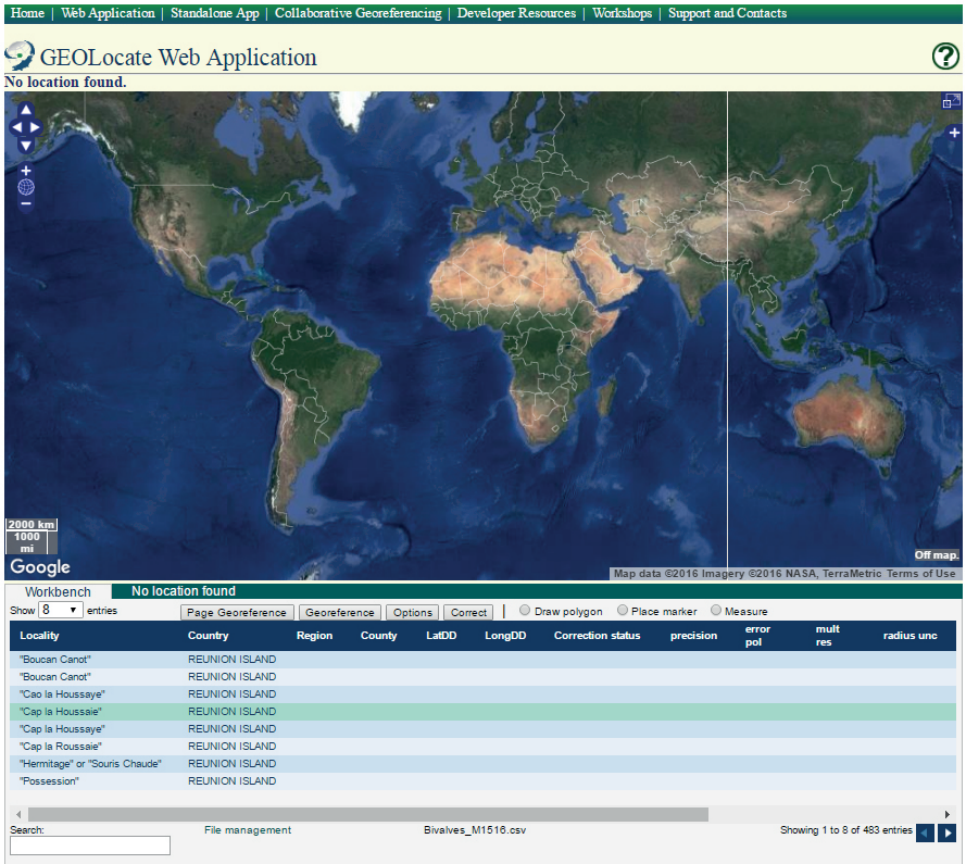

Figure 2. GEOLocate Web Application showing data being uploaded before the georeference process begins. The Georeference options allow changes before the application runs.

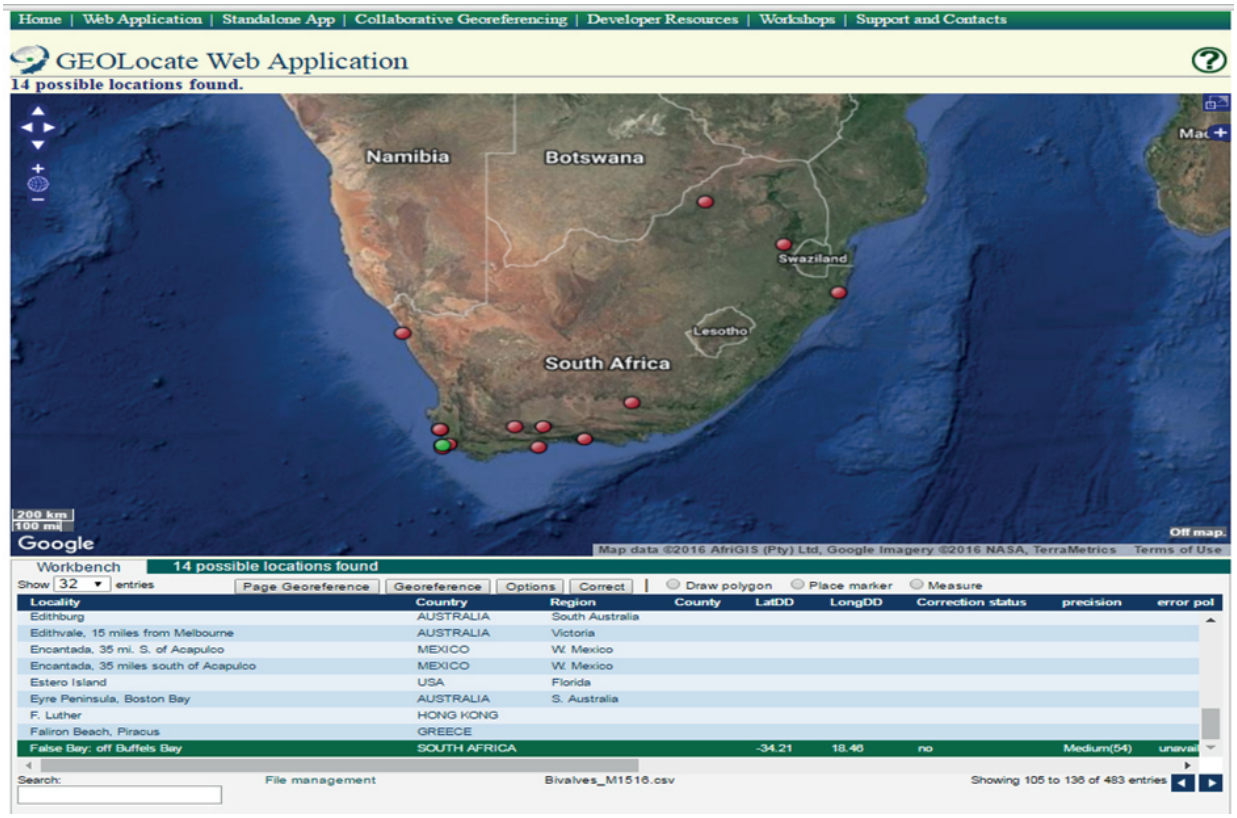

Figure 3. Example of georeference outcome for False Bay: off Buffels Bay in the Western Cape, South Africa, showing 14 possible locations found. 3a. The web application suggests that the green dot on the map is the correct location.

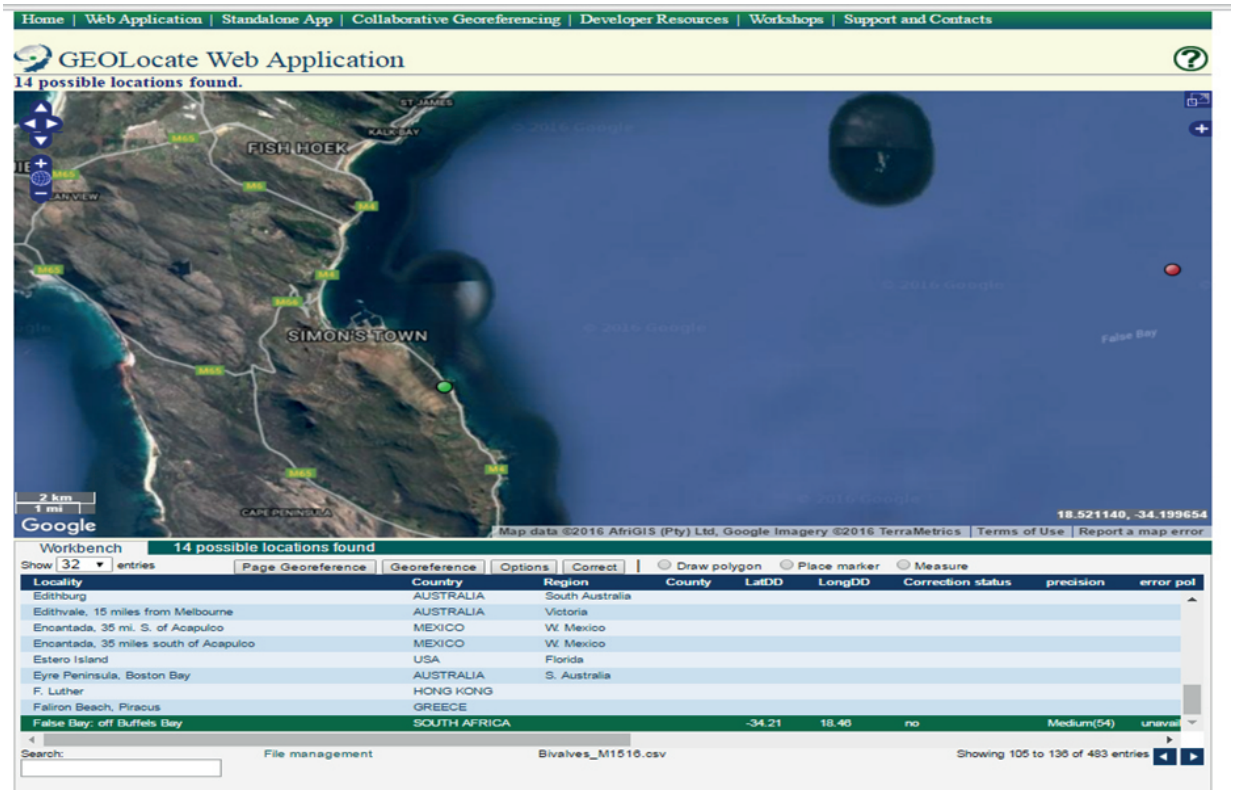

Figure 3b. By magnifying the map, it is clear that the green dot is off False Bay but located inland, in Murdock Valley.

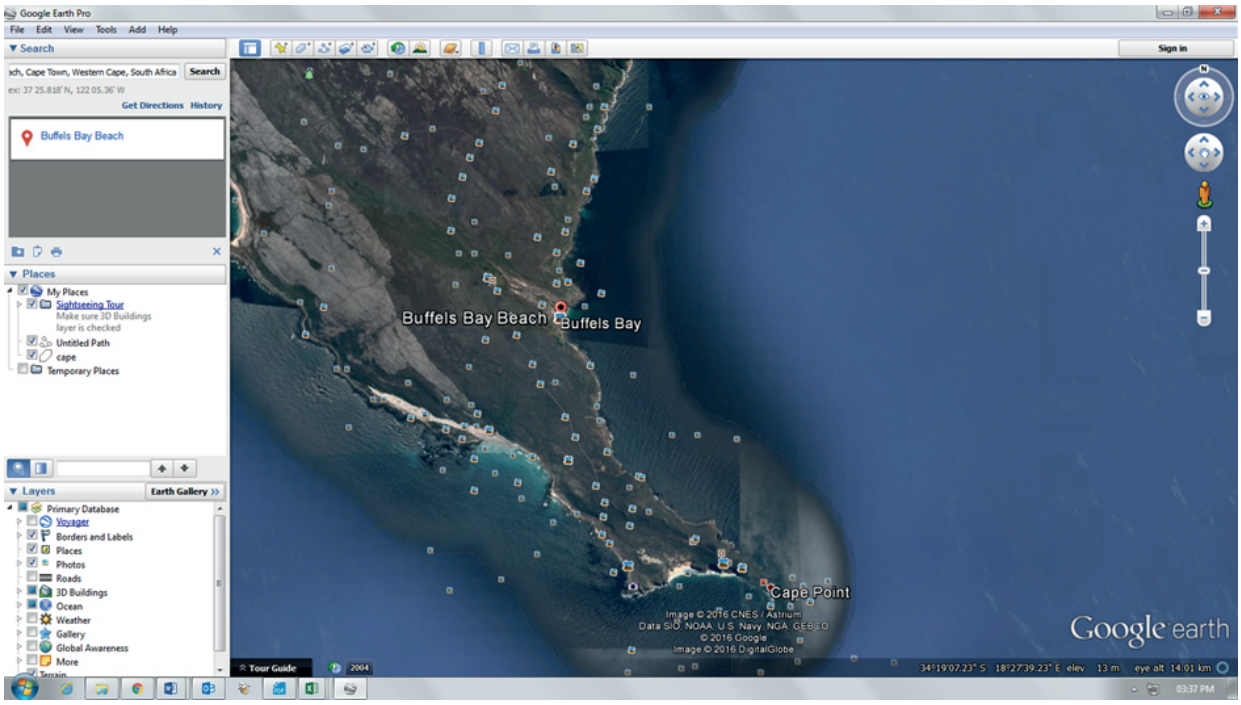

Figure 3c. Google Earth search for 'Buffels Bay' suggests that the correct location is not that suggested by GEOLocate in (a); it is the 'red dot' below the 'green dot'.

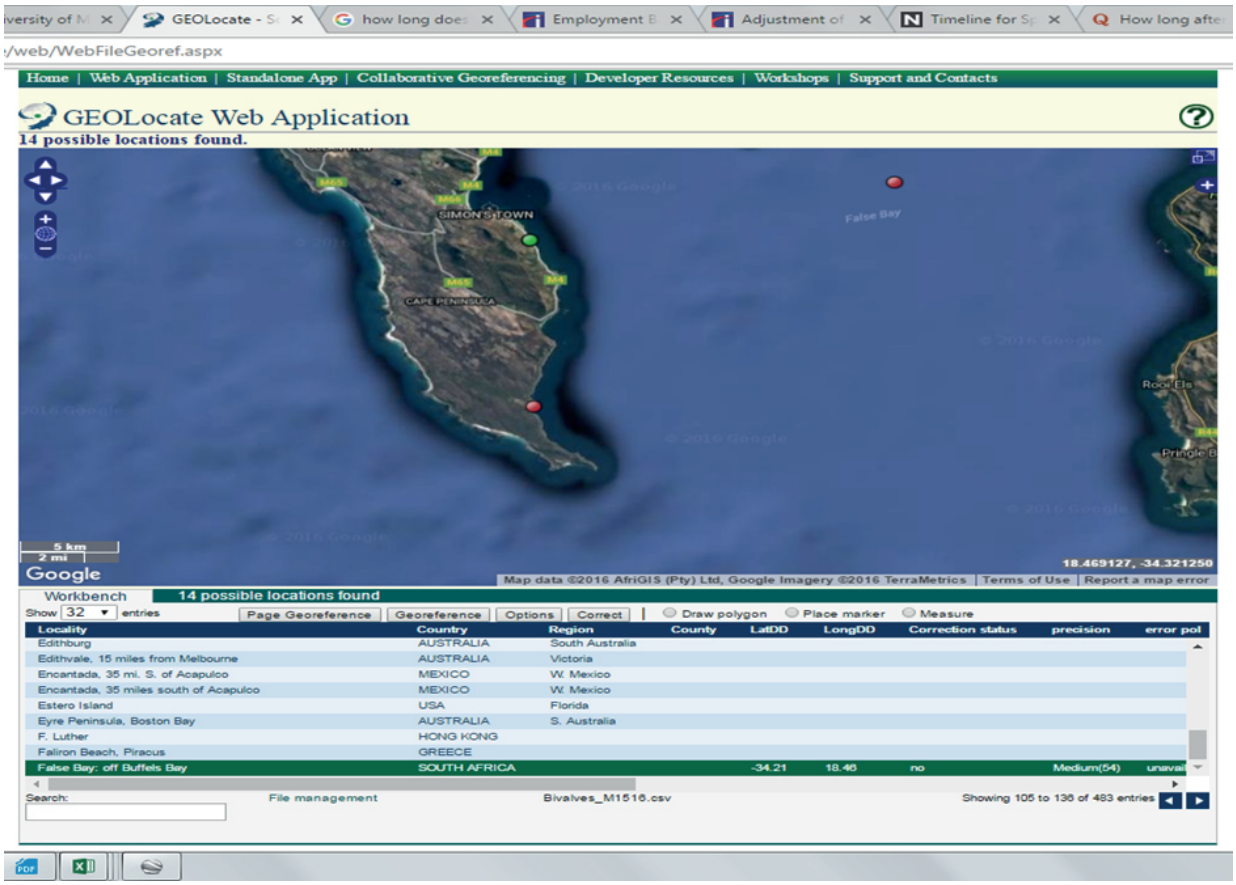

Figure 3d. The arrow pointing to the 'red dot' is the correct locality, and requires adjustment.

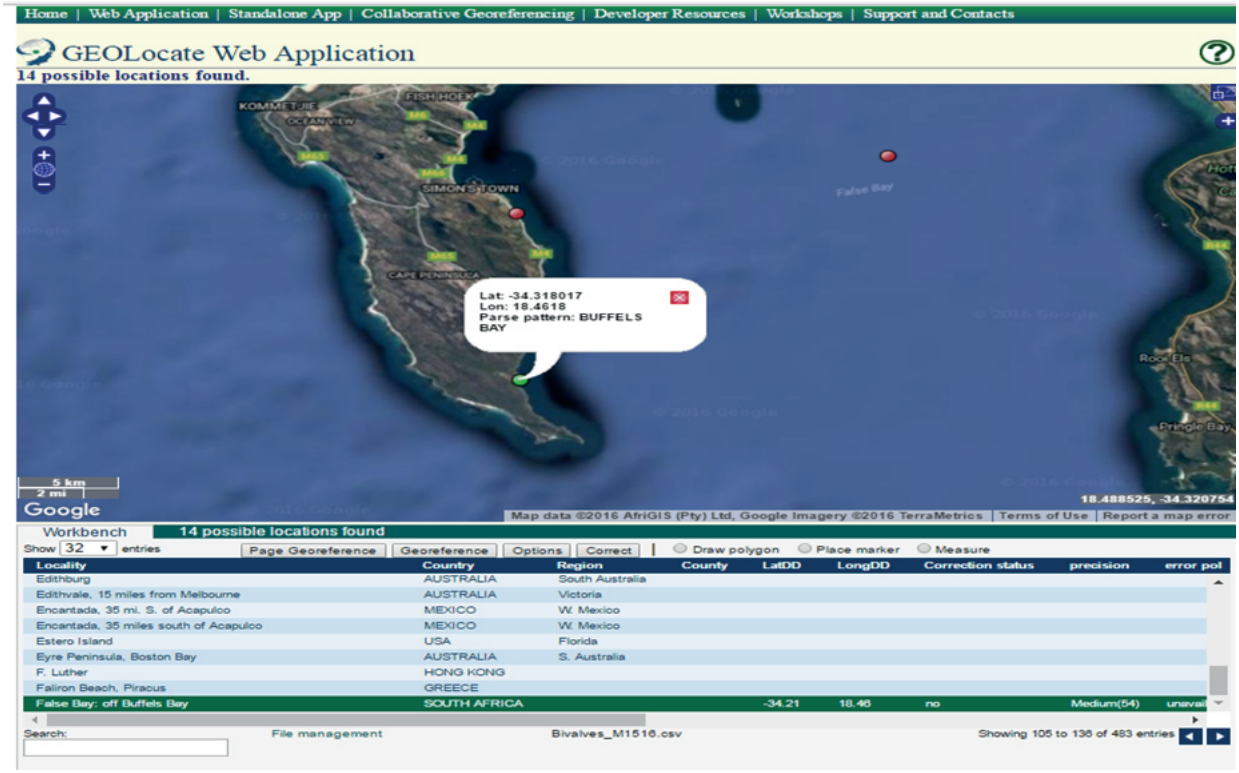

Figure 3e. The new 'green dot' shows the new corrected locality location.

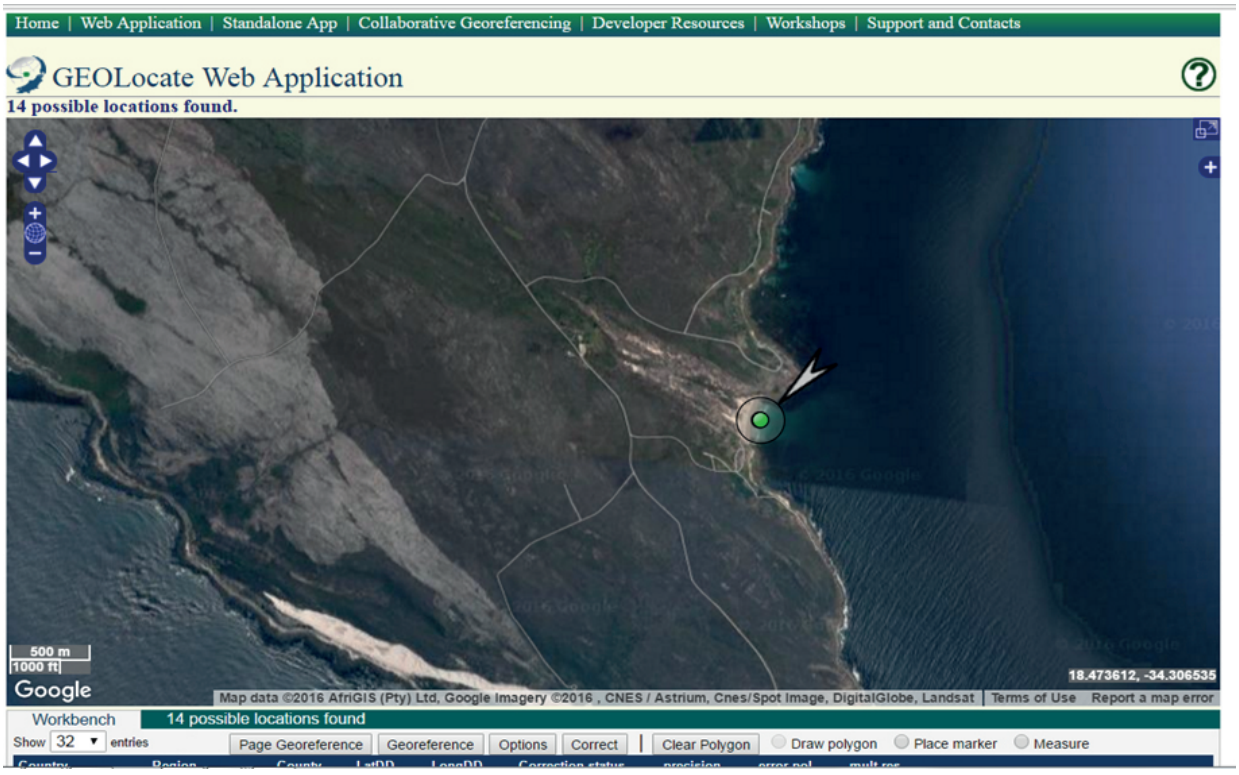

Figure 3f. The locality is marked with a circle around it, showing uncertainty in the locality description.

records', filtered to select records with latitude and longitude information only. All fields were deleted except 'accession number', 'latitude', 'longitude', 'lat.DD', and 'long.DD'. Before the column 'accession number', a new column labelled 'ID1' was again used as reference in case errors occurred during importing and merging of the two databases. In order to convert degrees, minutes, and seconds into decimal, five new columns were inserted next to the columns for latitude and longitude. Two more new columns named 'LatDD' and 'LongDD' were inserted and designated for the formula. After conversion to degrees decimal, the column of latitude South (S) was sorted first, followed by the column of longitude West (W) so that coordinates of South-West were marked negative. After this, the Excel file was exported into MS Access through a query which linked fields 'lat.DD' and 'long.DD to latitude and longitude of the main database, and precisely replaced all blank spaces.

Discussion and Conclusions

The issue of collection records not being 'fit-for-use' is huge and vital, but major concerns have focused on certain aspects of the problem (accuracy, management) without saying much about readability, tone, and interest. Perhaps one of the most exciting research directions for the use of database collections is to focus on how success through implementation of either digitisation or GRAP 103 projects is evaluated. Given the current biodiversity initiatives in South Africa, an immediate benefit to fully and effectively leverage these collections for research should not be overlooked. Even in their current state, the KwaZulu-Natal Museum collection databases have informed biodiversity projects nationally and internationally, and georeferencing the Bivalvia database has thoroughly added value to records that were poorly sampled. Data from this database have been used extensively in Professor Herbert's research publications, and supplied to the following national projects:

1. Distribution data on alien terrestrial molluscs for The National Status Report on Biological Invasions and their Management in South Africa in 2017. See: van Wilgen, B.W. and Wilson, J.R.U. (eds), in prep.
2. Distribution data on Karoo endemic snails used in the impact assessment for the proposed shale gas fracking in the Karoo. See: CSIR, 2016.
3. Marine mollusc data, including bivalves, will also be included in Atkinson, L. and Sink, K. (eds), in prep.
4. AfrOBIS: a marine biogeographic information system for sub-Saharan Africa. See: Grundligh et al, 2007.

As a research institution, it is important that our databases are correctly cleaned and accurately georeferenced with the fewest possible errors. Goodwin et al (2015) argue that data quality is an important consideration in herbarium digitisation, which is essential if the potential of herbaria for enhancing our understanding of key questions in systematics, biogeography, and environmental studies are to be realised (Penn et al, 2018). However, it is still recommended that the end-users of these datasets assess the quality and the accuracy of the data, in order to inform land-use planning and decision making. Robertson et al (2016) developed an R package, *biogeo*, tool for the detection and correction of errors (data cleaning) and for assessment of data quality of collections datasets consisting of occurrence records. This R package, *biogeo*, could transform museum collection databases, especially during data cleaning and quality assessment before or after data are georeferenced.

Georeferencing provides many advantages for data use in various capacities. For instance, the ability to identify geographical data gaps and to define priorities for collection. This is particularly important when aiming to link different data types and sources, such as floristic and trait data (Spehn and Korner, 2010). The other important value of georeferencing is the ability it provides to link the database's original content with other georeferenced data contained in other databases (Spehn and Korner, 2010). Although these were not implemented, it is anticipated that the digitised records (through georeferencing) of the Bivalvia collection database will ultimately be linked to other databases, and used to update coordinates to these other datasets. This strategy will allow coordinates from the Bivalvia database to be transferred to records of other databases with similar locality descriptions without undertaking the full exercise of georeferencing. In this way, valuable time and money will be invested effectively. Also, efforts to produce better and sustainable database collection management applications that maximise effective sharing of biodiversity information should be encouraged.

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Appendix I

Table 1. Major fields of the original Bivalvia database and their descriptions.

Field	Description
Accession no.	The catalogue number assigned to the specimen in the database.
Family	Family of the specimen by taxonomical classification.
Genus	Genus of the specimen by taxonomical classification.
Species	Species of the specimen by taxonomical classification.
Author	Person who first described the species.
Station no.	Number assigned to describe where the specimen was found. This number is rarely used for land snails but commonly used during collection of marine molluscs. The number is assigned to label the material, while information associated with the number is kept in the field book. This method simplifies re-writing of information on each label and makes it easier to query information on the label and in the field book.
Country	Country in which the specimen was collected.
Region	State or province within the country where the specimen was collected.
Locality	a) The position of a feature in space; b) The verbal representation of this position (i.e., the locality description) (Chapman and Wieczorek, 2006).
Latitude	Describes the angular distance that a location is north or south of the equator (degrees, min., sec.), measured along a line of longitude (*q.v*) (Chapman and Wieczorek, 2006).
Longitude	Describes the angular distance that a location is east or west of the prime meridian (*q.v*) (degrees, min., and sec.) on the earth's surface along a line of latitude (*q.v*) (Chapman and Wieczorek, 2006).
Depth/Altitude	How deep in the sea or height from the ground the specimen was found.
Day	Calendar day the specimen was collected (very important for database query).
Month	Calendar month the specimen was collected (very important for database query).
Year	Calendar year the specimen was collected (very important for database query).
Collector	Person(s) who collected the specimen.
Habitat	Brief description of the ecological place of collection.
Source	Information on whether the specimen was donated/purchased, etc.
Notes	Additional description of the locality and how the specimen was collected. e.g. Dived, dredged.
Determiner	Person who identified the specimen.
Other	Additional description of the locality and how the specimen was collected. e.g. Dived, dredged.
Cupboard	Place where the specimen is kept or stored in the collection room.
Institution	Organisation in charge of keeping the specimen eg. KZN-Museum.
Lat. DD	The latitude coordinate (in decimal degrees) at the centre of a circle encompassing the whole of a specific locality. Convention holds that decimal latitudes north of the equator are positive numbers less than or equal to 90, while those south are negative numbers greater or equal to -90. Eg. -42.5100° is roughly the same as 42°30'36" S (Chapman and Wieczorek, 2006). This is very important for mapping purposes.
Long. DD	The longitude coordinate (in decimal degrees) at the centre of a circle encompassing the whole of a specific locality. Decimal longitudes east of the Greenwich Meridian are considered positive and less than or equal to 180, while western longitudes are negative and greater than or equal to -180. Eg. -122.4900° is roughly the same as 122°29'24" W (Chapman and Wieczorek, 2006). This is very important for mapping purposes.
Entry date	Exact date the specimen was databased.
L/D	Live or Dead. If Live, it is usually followed by LPT (was found live, is Preserved in alcohol and Tissue was taken for DNA analysis).
Habitat type	Ecological niche description where the specimen was found.
Accuracy	How accurate are the GPS coordinates? Are the coordinates for the exact place where the specimen was found? Or for the whole region or game reserve etc.?
Collection date	Primary collection date of the specimen (in full format).
Databased by	The person who captured the record in the database.

Table 2. Examples of ambiguous and poor locality descriptions that did not provide geographic information during georeferencing of the Bivalvia database.

Locality	Country	Region	County	Habitat description
20 mí. East of San Juan, Bahia de San Juan	PUERTO RICO	San Juan	not georef.	Among strangled seaweed
Alexandra Junction	SOUTH AFRICA	KwaZulu-Natal	not georef.	
Anchor Reef, off Inhagonda area	MOZAMBIQUE		not georef.	
Labronico Sea	ITALY		not georef.	
Mainland	TANZANIA		not georef.	
Malaya	THAILAND	Penang	not georef.	
North Sea: Near Dogger	UK		not georef.	
Off Somali Republic	SOMALIA		not georef.	
Okhotsik Sea: Tauyskaya Guba, Nagaeva Bay	JAPAN		not georef.	
Persian Gulf: As Shaam	KUWAIT		not georef.	Sand among coral rubble

Table 3. Descriptions of fields included in the CSV spreadsheet for GEOLocate Web application tool.

** information should be filled through Google Earth search to identify the country/region they are currently associated with.*

*** information expected, otherwise geographic information will not be provided.*

Field	Description
Locality**	a) the position of a feature in space; b) The verbal representation of this position (i.e., the locality description).
Country*	State of entity.
Region*	State or province within the country where the specimen was collected.
County	If the locality cannot be found or is confusing, it was annotated 'not georef' and later checked for review. This is most convenient and can occur in the database itself. Attempt was made to correct the spelling (if applicable) or verify the locality description on Google Earth (Chapman and Wieczorek, 2006).
Lat. DD	See Table 1. If the locality description matches the spatial representation, geographic information will be added in Degrees decimal.
Long. DD	See Table 1. If the locality description matches the spatial representation, geographic information will be added in Degrees decimal.
Correction status	Labelled 'yes' if correction was made during evaluation and assessment of a record and 'no' if no georeferencing took place.
Precision	With measurements and values, it describes the finest unit of measurement used to express that value (Chapman and Wieczorek, 2006).
Error polygon	Geographic information will be added at the end of georeferencing.
Multiple results	Geographic information will be added at the end of georeferencing.
Radius uncertainty	The unit in length in which the uncertainty is recorded (eg., mi, km, m and ft).
Radius uncertainty (circular polygon)	The upper limit of the distance from the given latitude and longitude describing a circle within which the whole of the described locality must lie (Chapman and Wieczorek, 2006).
Habitat description*	Describe the ecological sphere of the habitat. e.g. Fine sandy and muddy.
ID	Assigned number to confirm and facilitate the export of georeferenced records into the main database. This number is assigned to both the accession number and the locality description during filtering and sorting of the main database so that it complies with the field requirements of the GEOLocate tool.

Identification Trainers for the Future: Developing the next generation of expert naturalists at the Angela Marmont Centre for UK Biodiversity

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Abstract

With ongoing losses to UK biodiversity occurring, the need for suitably experienced, passionate biologists who can identify and classify plants and animals, and engage young people with the natural world, has never been greater. There has, however, been a decline in biological field skills, particularly in emerging scientists and graduates, in recent years. This is due to a combination of factors, including our changing relationship with nature, reduced childhood engagement, and a lack of education and training opportunities. Cuts to museum specialists have also occurred, making it more difficult for early career professionals to gain the training required to work in field ecology, taxonomy, and as specialist curators.

The 'Identification Trainers for the Future' traineeship, launched in 2015 by The Natural History Museum (NHM) in partnership with the Field Studies Council (FSC) and the National Biodiversity Network (NBN), and hosted within the Angela Marmont Centre for UK Biodiversity (AMC), is a strong example of how early career professionals can develop ecological field and curatorial skills. It provides a platform for passionate individuals to train future generations in wildlife identification, support naturalist groups, and engage public audiences to connect with the natural world. This paper outlines the aims and key elements of the ID Trainers for the Future traineeship, reflecting on personal experiences. Finally, the paper outlines initial lessons learnt and next steps as the active phase of the programme draws to a close with the final cohort of trainees in spring of 2018.

Keywords: traineeship, conservation, biodiversity, taxonomy, field skills, curatorial skills, citizen science

Why is there a need for the 'Identification Trainers for the Future' programme?

Wildlife and green spaces are fundamental to our human experience, health, and emotional wellbeing. However, social and technological changes, and the fact that nearly 85% of people now live in urban areas in the UK (Denham and White, 1998), have led to a lack of opportunities for people, particularly the young, to engage with wild places. The Natural Environment White Paper published in 2011 states that "*Children are becoming disconnected from the natural environment. They are spending less and less time outdoors. In fact, the likelihood of children visiting*

any green space at all has halved in a generation." (Her Majesty's Government, 2011: p12). Children aged 11 to 15 years, on average, now spend over half of their waking lives in front of TV and computer screens (Sigman, 2007a). This has led to the coining of the term 'concrete children', who spend much of their time indoors, in urban environments, with little or no access to nature or the countryside (Sigman, 2007b).

Professor Simon Leather, course leader for the MSc in Entomology of Harper Adams University has articulated the clear links between the impact of reduced engagement with nature and the lack of identification skills of young people and the public at large (Leather and Quicke 2010). Leather and Quicke (2009; 2010) highlight the inadequacy of primary, secondary, and A Level education to equip young people with identification skills prior to university, and reflects on a decline in these skills among undergraduates. School teachers are not well trained to deal with taxonomic issues, and secondary biology teachers, on average, are unable to identify more than three species of common British wildflowers (Bebbington, 2005 in Leather, 2009). Bebbington (2005) noted that "*conversations with* [A level biology*] students suggest a general feeling that being able to name organisms is not important to them and that they have little interest in acquiring identification skills*."

Environmental campaigner George Monbiot (2012) states that if children are less engaged in the natural world, it will be far more difficult for them to develop the awareness and skills required to monitor and protect it. Papworth et al. (2009) have also recognised that if you are unaware of change around you, you cannot be expected to engage with conservation of the environment.

In September 2016, the State of Nature Report revealed that UK biodiversity is in a precarious situation, following historic industrialisation, deforestation, intensive agriculture, habitat loss, pollution, introduction of non-native species, and climate change as a result of human activity. One in ten species is now threatened with extinction, and nearly two thirds (59%) have declined since 1970. The UK is ranked 189th in the world in terms of its 'biodiversity intactness' (Hayhow et al., 2016). The effective monitoring of UK biodiversity can only take place if there are skilled taxonomists and field naturalists able to collect and analyse data. The House of Lords Science and Select Committee has expressed concerns about the decline in the UK's taxonomic capability (House of Lords, 1992; 2002; 2008), which they have argued undermines its ability to monitor its own biodiversity, ensure environmental sustainability, and meet its international commitments.

A study by the Linnean Society (Cutler and Temple, 2010a,b) reported that the number of professional taxonomists is declining. A Natural Environment Research Council (NERC) strategic review of UK taxonomy highlighted concerns over the failure to replace retiring taxonomists with future generations (Natural Environment Research Council, 2010). Michael Parkin (2015) argued that the decline in biological field skills in emerging scientists, particularly at graduate level, "*has reached crisis point*". He estimated that there are fewer than ten UK graduates each year who are proficient enough in field identification skills to be employable as field ecologists. The role of biodiversity monitoring has become increasingly reliant upon those operating on a voluntary basis (Lyal, 2005), whilst some 'amateurs' are the acknowledged experts for their particular organism group (House of Lords, 2008). However, "*volunteers are not a substitute for trained professional taxonomists, but complement their activity*" (Cutler and Temple, 2010a).

The decline in skilled field biologists has been mirrored by the loss of curators and subject specialists in museums, in the wake of severe cuts to museum funding as a result of austerity measures following the financial crisis of 2007 (Evans, 2012; Viscardi, 2013; Hall, 2015). The continued cuts to curatorial expertise threaten the ongoing care and conservation of natural science collections, their accessibility for research, and usefulness for biological recording, as well as training in identification and taxonomy. There has also been a shift in museum priorities to fund outward-facing public engagement and education activities as opposed to traditional curatorial roles (Kemp, 2015).

Reduced childhood engagement with nature and the systemic failings in the formal education system cited by Leather and Quicke (2009; 2010) have impacted negatively on the opportunities for young people to connect with nature and develop basic identification skills. Therefore, there is a need to train a new generation of suitably qualified natural history specialists, who can in turn inspire and train future generations to understand UK biodiversity.

Meeting the skills gap: field and taxonomic skills training within the UK

The 'Identification Trainers for the Future' programme, led by the Natural History Museum in partnership with the Field Studies Council (FSC) and the National Biodiversity Network (NBN), was developed to address the reduction in ecological field skills and taxonomic training. This programme sits alongside a variety of traineeships, identification training and postgraduate courses that have successfully enabled people, especially young people, to develop biological field skills, taxonomic knowledge, and curatorial skills.

One of the most successful examples of naturalist skills training is The Conservation Volunteer's (TCV) Natural Talent Traineeship programme. The aim of the programme is to increase expertise across the whole of the UK, to protect our less well-known species and create awareness of the habitats that support them (The Conservation Volunteers, 2017a). Initially funded by the Heritage Lottery Fund (HLF) up to 2016 (previously known as the Natural Talent Apprenticeship programme) and now supported by the Esmée Fairbairn Foundation, it has enjoyed considerable success, having delivered 44 apprenticeships between 2006 and 2016 (ibid). The one-year traineeship allows individuals to develop expertise in a specific taxonomic group, habitat, or a mixture of both through placements with environmental charities, record centres, and museums (ibid).

Lancashire and London Wildlife Trust's one-year traineeships are focused on gaining core skills in conservation, volunteer and community engagement (Lancashire Wildlife Trust, 2017; London Wildlife Trust, 2017). Lancashire's 'Biodiverse Society' project is an HLF-funded project to address a skills shortage within the environmental conservation sector. Trainees spend a year gaining practical conservation skills including volunteer leadership, biological recording and species identification, and survey skills, with a strong focus on developing community engagement skills. This is achieved through in-house and external training, a personal project, and on-the-job experience (Lancashire Wildlife Trust, 2017). London Wildlife Trust's 'Wild Talent' traineeship also aims to diversify the workforce, as it only accepts applications from people in receipt of benefits, without a higher education qualification, of black and minority ethnic (BME) origin, or from an economically deprived area of London (London Wildlife Trust, 2017).

There are other well-coordinated programmes of identification training across the UK, and it would be impossible to list them all here. These include training provided by environmental record centres, societies, and museums, which all aim to address the shortage in field skills. Examples include the FSC, a leader in field teaching for schools, colleges and universities. They offer comprehensive field identification courses across terrestrial and marine animals and plants, ecology and conservation courses, and professional taxonomic training (Field Studies Council, 2017a). The Marine Biological Association (MBA) also has an excellent track record in delivering a variety of bespoke training courses and workshops for all levels of expertise, including species identification courses, survey skills, practical skills for marine scientists, and scientific Illustration.

There are also several University postgraduate courses aiming to provide high quality identification and fieldwork skills. To meet the shortage of skilled entomologists and specialists in conservation and agriculture, with specific reference to the future challenges of food security, the MSc in Entomology at Harper Adams University is the only postgraduate course to teach general and applied entomology, and includes a module on taxonomy (Harper Adams University, 2017). Other postgraduate courses offering identification and field training across a range of taxonomic groups include the Msc in Biological Recording at Manchester Metropolitan University (MMU) in association with the Field Studies Council and the Botanical Society of Britain and Ireland, and the Msc in Conservation Management at Edge Hill University.

HLF's 'Skills for the Future' museum training programme (2009 – 2016) aimed to fill skills gaps within the sector (Randell, 2016). As part of this scheme, 16 one-year curatorial traineeships were run from April 2011 to May 2015, initially by Herefordshire Museum Service and subsequently by Birmingham Museums Trust (BMT) from 2013. The programme was run in partnership with several organisations, including the Natural Sciences Collections Association (NatSCA) and NHM. It allowed trainees to gain experience of working in the museum profession under the supervision of experienced curators (Birmingham Museums Trust, 2015). 16 trainees went through the programme, and traineeships were tailor-made to suit individual development needs, providing trainees with the skills to become curators of natural history, ceramics, decorative arts, social history, and agriculture history collections.

The 'Identification Trainers for the Future' HLF Skills Programme

Project Aims:

- Host 15 12-month, work-based traineeships at the NHM supported by FSC and NBN partners
- Trainees will support the UK's taxonomic skills base by focusing on developing UK biodiversity identification, biological recording and museum skills
- Trainees support the work of the Angela Marmont Centre for UK Biodiversity (AMC) as a hub for partnership-based UK natural history information, engagement, training, citizen science and research working with the Identification and Advisory Service, citizen science and curatorial teams (Angela Marmont Centre for UK Biodiversity, 2017)

The 'Identification Trainers for the Future' (or 'ID Trainers for the Future') programme has been funded by the Heritage Lottery Fund (HLF) from 2015 – 2017, and seeks to address the critical and growing shortage of wildlife identification and recording skills in the UK (Natural History Museum, 2016a). It has, to date, provided 15 enthusiastic and committed early career naturalists with work-based training to gain the knowledge, confidence, and skills needed to understand and communicate the value of biological recording, to survey and identify a wide range of UK taxa, to specialize in a particular group, and to handle and curate reference specimens. Importantly, the trainees also develop science communication, teaching and public engagement skills in order to train others.

The programme provides for the training of five candidates a year in UK biodiversity, biological recording, ecological field skills, and curatorial skills (Natural History Museum, 2016a). These subjects are taught by leading scientists, field ecologists, and curators. Steph West, Project Manager of the Identification Trainers for the Future Project, states that: "*Our most highly skilled species identifiers and taxonomists are often amateurs and many of them are at, or beyond, retirement age. Younger ecologists are leaving universities with great qualifications but without the detailed knowledge of a true specialist…often graduates leave university with very little idea of how to start developing their skills in this area and very little exposure to field recording. We want to help turn this situation around via our traineeship scheme.*" (Natural History Museum, 2016b).

The Angela Marmont Centre for UK Biodiversity (AMC)

Throughout the 12-month traineeship, trainees are based in the AMC, which sits within the NHM's Darwin Centre. The AMC's core goal is to further the appreciation, study and understanding of the UK's natural history. The AMC forms a focus for a wide range of projects that, together, aim to address two of the central problems facing UK biodiversity and geodiversity science:

- How to inspire and support existing and future naturalists
- How to actively engage the wider public in natural science

The AMC's mission is to inspire and support existing and future naturalists, by working closely with the UK's amateur-expert naturalist community (Angela Marmont Centre for UK Biodiversity, 2017). This is to ensure the continued stability and expertise in taxonomy and systematics needed to describe, record and monitor the UK's biological and geological diversity during a time of major environmental challenges (Ibid). The core staff of identification officers, ecologists, curatorial and citizen science professionals are supported by expert scientists from across the Darwin Centre.

The AMC hosts the Identification and Advisory Service, which is provided by a dedicated team of Identification Officers whose job it is to work with members of the public, and commercially, to identify natural history finds. The Identification and Advisory Service provides support for people of all ages and abilities to identify their specimens of wildlife, fossils and other geological finds either face-to-face, over the phone, by post, or the online NaturePlus forum (Angela Marmont Centre for UK Biodiversity, 2017). With the help of the Identification Officers, visitors can learn more about a species group or aspect of UK biodiversity, access reference collections and training opportunities, as well as information about how to access naturalist groups near them.

The AMC is also responsible for the UK Species Inventory, a database of the names of all British wildlife that is used by most UK biological recording and reporting systems. The AMC's UK reference collections, including the British and Irish Herbarium, British Entomology Collection, and the library of the London Natural History Society (LNHS) are excellent resources with which aspiring naturalists can hone their identification skills and passion for the natural world (Natural History Museum, 2016c). The AMC

provides workshop spaces, which can be booked out free of charge by naturalist societies. Regular users include the Earthworm Society of Great Britain, the Conchological Society of Great Britain and Ireland, and the Botanical Society of Britain and Ireland.

The Traineeship Experience

Anthony Roach (AR) was selected as one of the five candidates for the first cohort of the 'Identification Trainers for the Future' traineeship programme (March, 2015 – February, 2016) (see Figure 1). The rest of this paper will be devoted to the traineeship experience, including Roach's personal insights (shown in italics) and the authors' contribution to the public engagement activities of the AMC, lessons learned, and outcomes of the programme.

Figure 1. Cohort 1 of the ID Trainers outside the AMC Image: Stephanie West (Right to left - Sally Hyslop, Mike Waller, Katy Potts, Anthony Roach, Chloe Rose). Image: A. Roach.

The 'ID Trainers for the Future' traineeship was taught in four key phases. As the traineeship consisted of work-based training, trainees were expected to develop a training portfolio, comprising reviews of each of the phases, ID workshops and FSC placements, a weekly Personal Journal to track progress, associated blog entries, detailed notes and identification resources, and examples of project work, to form a detailed record of experiences. This was produced alongside a formal *Record of Training*. From the outset of the training, both individually and as a team, trainees were expected to contribute to the writing of blogs and other publications about our experiences, both internally at the NHM and with our NBN partner, as well as presenting at the annual NBN Conference.

Phase 1: Introduction (1 Month)

Phase 1 focused on museology, object handling and conservation, natural history collections best practice, and an overview of UK biodiversity from the Holocene to the present day. It also included professional development training, a detailed study of taxonomy and taxonomic delimitation, and visits to the Linnean Society of London to understand the history and development of Linnaeus' system of classification and the contribution made by founding naturalists such as Sir John Ray and Sir Hans Sloane (see Figure 2). With the NBN as a major partner, Rachel Stroud, NBN Data Officer throughout the traineeship, provided excellent support, both from the perspective of a data manager and as a mentor. Stroud delivered a number of courses, the first of which was on the handling and use of biological data. Alongside this, courses on the handling and pinning of entomological specimens, field skills, and fieldwork first aid provided a strong foundation on which to develop curatorial and naturalist skills in preparing reference collections. Trainees also attended a series of professional skills training courses, including Communication and Influencing Skills, Assertiveness, Team Working, Time Management and Networking.

Figure 2. The ID Trainers pictured during a tour of the Linnean Society of London to learn about the founding naturalists and father of taxonomy Carl Linnaeus. Image: A. Roach.

Phase 2: Developing core skills (5 months)

Phase 2 focused on developing core knowledge of key taxonomic groups through a mixture of practical lab identification and field survey courses, and a work placement within the AMC, moving between the Identification & Advisory Service, the Citizen Science team, and later assisting with the Public Outreach programme. Identification courses included lichens, mosses, freshwater invertebrates, beetles,

earthworms, and moths (a full list can be found on the ID Trainers website (Natural History Museum, 2016a)). Usually, three to five days were spent with curators and field ecologists, in order to familiarise oneself with the group, understand the core characters for identification, collect specimens in the field, and learn techniques for creating reference collections. This included handling and pinning techniques, and time spent identifying specimens using keys and reference collections (see Figure 3). Phase 2 also included teaching placements with Primary and Secondary School students at The Old Malthouse residential school in Purbeck, Dorset.

Figure 3. Coleoptera identification training. Image: A. Roach.

With the FSC as a major partner, each ID Trainer was able to choose two field placements, the first of which was shadowing and assisting at a Field Studies Council Centre, which involved taking part in field teaching with school and public audiences. The second field placement was an identification course based around a specific taxon or area of interest, in order to begin developing a specialism.

Due to my interest in invertebrates, and a desire to improve my knowledge of flowering plants, I chose Flatford Mill as my FSC Centre, where I was able to observe the workings of the centre and shadow two courses ('Wildflower Identification: Top 20 Families' and 'Identifying and Sampling Freshwater Invertebrates', which was held at Flatford Mill in Suffolk). Over the course of the 10 days, I spent time assisting the field tutors in sampling, and could confidently use a variety of identification keys and understand techniques for freshwater sampling. All of these courses had common elements: focused identification training, field surveying and teaching, and opportunities to take part in the life of an FSC Centre. For example, fellow ID Trainer Sally Hyslop came face to beak with puffins on the Welsh coast at FSC Dale Fort; Mike Waller was able to indulge his passion for plants and ancient relic landscapes at FSC Malham Tarn; Chloe Rose discovered seashore life at FSC Millport; and Katy Potts found stunning alpine plants at FSC Rhyd-y-creuau. My third course, along with the other trainees, was in identifying fungi and held at the base of the Cairngorms National Park.

Phase 3: Developing a Specialism (3 months)

In Phase 3, trainees were given the opportunity to refine their identification skills, develop detailed knowledge of a species group, and develop curatorial skills on a specialist collection. Identification training was provided in Dorset, with ecologists from the AMC. Trainees undertook bat surveys and moth trapping, and learned more about Studland's wildlife, as well as the coastal plants of the Isle of Purbeck.

A list of curatorial projects was put forward by NHM curators, based on understudied areas of the collections. These ranged from re-curating Dr Francis Rose's lichen collection, creating a key to British parasitic wasps of the genus *Alexeter*, to assessing the beetle fauna of Bookham Common in Surrey. More information about the various curation placements can be found by visiting the ID trainers blog (Natural History Museum, 2016d).

I was asked to re-curate the existing collections of late 19th and early 20th century UK dragonflies and damselflies (Odonata). There are currently 45 resident species of dragonfly in the UK. Historically, they were some of the first entomological specimens to be collected, featuring in the early 17th century collections of James Petiver and Sir Hans Sloane. My first job was to remove the specimens from their old cork-lined drawers and place them into new plastazote-lined unit trays. The specimens themselves were incredibly delicate, and needed to be handled with precision. Often, very old pins suffer from Verdigris, which can easily destroy the body of an insect. Each specimen was individually barcoded with a small label made from archival standard card that was attached to its pin. The label contained a unique specimen number. A specimen-level record was then produced for each specimen in the collections management system Ke-Emu, and the taxonomy was updated to take into account changes to Odonata classification.

One of the elements of this three-month curatorial project was to create a synoptic collection of each British Dragonfly species. This was accomplished by going systematically through the existing British collection and, where possible, identifying one male and one female to represent each species, along with sub-species and colour variants of each species (see Figure 4). This helped me to really understand the identification of UK species

of Odonata, by studying the abdominal segments, eye colour, and colour variations of the same and different species. The project also resulted in a set of specimens that can be used for publication and public engagement activities. Imaging the collection was something Dr. Ben Price was keen to do, in order to generate more information about the collection. I was asked to undertake image label testing to determine angles for data labels to be read and eventually electronically transcribed using computer software. The label image testing and digitisation were also undertaken to improve the accessibility of the collection for future research.

Figure 4. Some of the specimens from the newly created Synoptic

Phase 4: Skills transfer and training delivery (3 months)

Phase 4 allowed the trainees to consolidate what they had learned by developing a useful written or practical teaching resource for identification. This could be an online key or guide to aid the identification of a species group, a resource to be delivered as part of an identification workshop, or a 'how to' guide to running a bioblitz, workshop or other practical identification training session.

Final elements of the traineeship were dedicated to ensuring trainees were equipped with training and teaching delivery skills. Two weeks were spent with both NHM's Science Educator team and assisting the Learning Volunteer Program, to develop the trainees' knowledge of learning theory and object–based learning with museum audiences. All trainees completed a Level 3 Award in Education and Training, awarded by Ofqual, which was taught by the Field Studies Council and delivered at Blencathra Field Centre in the Lake District. This provided a further foundation in the approaches to learning theory, understanding the roles and responsibilities of teachers, lesson planning, and teaching delivery.

In Phase 4, I ran an identification training course for fellow trainees on spider identification at Blencathra Field Centre. This was part of my assessment to gain a Level 3 Award in Education and Training. I was required to build on previous spider identification guidance, and simplify terms and identification characters to ensure it was more inclusive and suited differing abilities.

Towards the end of phase 4, I requested to work with the NHM's Conservation team. I was very fortunate to work on the Blue Whale skeleton which is now displayed in Hintze Hall. During my brief period helping On this project, I spent time removing the old wire armature, cleaning using conservation grade materials, and photographing the chevrons on the underside of the tail vertebrae. It was a fantastic opportunity to see the blue whale skeleton up close, and talk to the public about the conservation work.

Citizen science at the Angela Marmont Centre for UK Biodiversity

The AMC has a strong track record of developing innovative citizen science projects that allow both online and field-based participation in UK wildlife, to inspire future naturalists. As an ID Trainer for the Future, AR was able to manage and assist in public engagement through two citizen science projects, the 'Big Seaweed Search' and 'Orchid Observers' (Natural History Museum, 2016e).

The Big Seaweed Search

The Big Seaweed Search is a citizen science project that engages people of all ages to monitor the effects of environmental change on Britain's shores, by exploring the seashore and recording the living seaweeds that they find there. It asks the public to record eight seaweeds that are influenced by sea temperature rise, four non-native species to monitor their spread, as well as finding evidence of ocean acidification through the presence of coral crusts and coralline seaweeds (Natural History Museum, 2016f). The project was established in 2009 as a joint project between NHM and the Open Air Laboratories (OPAL), and was launched at the Wembury Bioblitz event. During this bioblitz, an incredible 823 different kinds of plants, animals, and fungi were recorded in a 24-hour period (Marine Biological Association, 2009). The project was relaunched in 2016 as a joint NHM-Marine Conservation Society project. Before it's relaunch, The Big Seaweed Search had generated over 1700 individual observation records, with over 300 participants recording Seaweeds across the British Isles.

My involvement in the Big Seaweed Search project involved delivering public outreach, working with marine scientist Juliet Brodie and Citizen Science Project Manager Lucy Robinson to evaluate the success and reach of the project, and write a summary report to 2015. In preparation for a re-launch, I was asked to develop a web design brief to refresh existing web content, manage enquiries, and work with new and existing stakeholders to launch a new and updated survey that considered new science research questions, alongside the original ones.

Orchid Observers

The Orchid Observers citizen science project was developed by the NHM in partnership with Zooniverse, and aims to investigate how the flowering times of 29 UK species of orchids are being affected by climate change. A secondary aim was to understand how volunteers share ideas and knowledge with one another (Robinson, 2016). The project asked the public to take photographs of any of the 29 species and upload them, identify species in photographs that others have uploaded, and/or transcribe herbarium sheet information for NHM specimens. Online participation generated interest in NHM's existing herbarium specimens from volunteer and naturalist communities, and enabled the public to contribute to real scientific data by finding and photographing orchids across the UK during the flowering season, and uploading records. The project saw over 2000 volunteers take part, and produced more than 1800 new observations of wild orchids (Robinson, 2016).

Outcomes and Lessons Learnt

The 'ID Trainers for the Future' programme provides trainees with the taxonomic grounding to further develop their careers as specialists, albeit alongside further on-the-job training and academic study. Having specialists in entomology, field ecology, UK biodiversity, citizen science, and identification all in one place within the AMC made a great difference to the development of the trainees. The support given throughout the programme, including mentoring for projects and future careers preparation, helped all five trainees in the first cohort gain positions within the conservation and ecology sector within six months of completing the traineeship. Cohort two are now also fully employed, variously at the NHM, Natural England, and the Hampshire Wildlife Trust. This demonstrates that the skills and training provided by the programme are valuable to employers, in a highly competitive sector.

The project team are now drawing together evidence for full evaluation of the project, as the traineeships themselves reach their concluding stages. A full report and associated seminar will be announced early in 2018, which will not only celebrate the success of the project and the trainees, but also share the lessons learned from running the project and look forward to the legacy of the work. Some statistics on the delivery of skills training as a result of the ID trainers course, and the development of biodiversity skills in the AMC, are outlined below (West and Tweddle, 2017).

Training delivered with the ID Trainers for the Future:

- 62 Taxonomy Workshops
- 53 site visits
- 48 Employability skills workshops
- 33 NHM experts delivered training
- 172 non-trainee participants

Developing Biodiversity skills in the AMC (2013-17):

- 1.3k attending training workshops
- 46.3k participants in field-based citizen science
- >35k face-to-face interactions at events
- 12.4k public enquiries answered
- >75k downloads of ID guides and apps

Although the project is now drawing to a close, it has had a profound impact on the ways of working within the AMC and the wider NHM. The identification materials the trainees have produced over the past three years will remain available to all long-term through our website, and we will be adding to these as the final projects are completed over the next few months. In terms of the wider aims of the project, however, not only has the project challenged us to look at new ways of recruiting, but has enabled us to look into the question of encouraging diversity in new applicants, a known significant issue both for the museums sector and the UK biodiversity sector. Information and networks gathered through the project have enabled us to look more broadly at diversity issues within the NHM, and this has assisted in the formation of a cross-departmental diversity working group within the Museum.

In terms of training delivery, a new post of UK Biodiversity Training Manager has been created within the Angela Marmont Centre, and currently a strategy for training in UK natural science is being

formulated which will steer the future training offer from the UK Biodiversity Centre. Examples include expanding on opportunities to deliver taxonomy courses around the key taxa covered by the trainees to all interested parties as 4-5 day workshops. The aim is to build on the framework of training which was developed for the ID Trainers project, and to expand and broaden this offer in a way that will not only support early-career natural historians, but also the existing natural science networks, as well as encourage, engage, and enthuse audiences who may not previously have considered natural science as a viable and interesting career.

The life of an ID trainee was a challenging and rewarding experience. It provided me with an excellent grounding in species identification, and I benefited in a host of other ways. This included understanding the value of biological recording to biodiversity study, environmental monitoring, and conservation. I gained a strong understanding of taxonomy, use of appropriate field techniques, the ability to identify organisms to family and species level, and curate and use reference and field voucher specimens to do this. I gained an understanding of systems for managing biodiversity data, and developed a specialism in freshwater invertebrates. Through placements with the Field Studies Council, and benefiting from the National Biodiversity Network, I developed a strong awareness of the individuals, voluntary groups and professional bodies who contribute to the biological recording effort in the UK and the data flow pathway. I further enhanced my professional development and public engagement skills by gaining a teaching qualification, and was able to put my teaching and identification training skills into practice. This has ultimately benefited me in joining Earthwatch Institute, where I develop citizen science training for schools and community groups.

Conclusion

As the current biodiversity crisis worsens, and children continue to spend more time indoors and away from nature, it is vital that museums and scientific institutes support the development of subject specialists who can continue to inspire young people to take an interest in the natural world, and to encourage them into scientific careers. Passionate experts in museums can provide meaningful opportunities for public audiences, particularly the young, to connect with nature. Supporting future naturalists is something that can be achieved through training, public engagement, and citizen science activities undertaken alongside passionate experts, as demonstrated by the 'ID Trainers for the Future' programme at the Angela Marmont Centre for UK Biodiversity.

The 'Identification Trainers for the Future' programme is one example of a scheme that aims to halt the observed decline in the number of specialist taxonomists by enabling graduates and early career professionals to develop their field ecology, identification, and curatorial expertise. All five trainees in both the first (2015-16) and second (2016-17) cohorts went on to secure jobs in the ecology and environmental sector within six months of completing the traineeship. Meanwhile, 90% of TCV's Natural Talent trainees were employed into the conservation sector soon after completing their traineeships (Horsley and McFarlane, 2017), and 70% of Birmingham Museums Trust's HLF trainees had already gained employment after completing their training (Birmingham Museums Trust, 2015). This demonstrates that traineeships are an effective way of filling skills gaps in biological recording, curation, and conservation, alongside universities and other training providers.

These traineeship schemes have shown that on-the-job skills training can build successful careers in conservation and museums. The future is therefore more positive for new generations of naturalists, and for wildlife conservation in the UK.

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Fossil hunting and grinding in the Coal Measures: William Cash (1843-1914), his associates, and their work on the fossil plants of the Carboniferous period

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Abstract

William Cash (1843 – 1914) was an important amateur palaeobotanist based in Halifax, Yorkshire, but with connections at Owens College, Manchester. He worked with both the important amateur and professional palaeobotanists of the day, including Professor W. C. Williamson at Manchester. His important collection of over 700 microscope slides is at Manchester Museum. These slides have been scanned and catalogued, and include specimens mounted by associated workers of the time. Other museums in Britain have related material.

Keywords: William Cash, William C. Williamson, Thomas Hick, plant fossils, microscopy, slide preparation, slide collection, Manchester

Introduction

Botany was a popular subject amongst amateur, especially working class, naturalists living in southwest Yorkshire and the areas around Manchester during the period when William Cash was active (late 19th – early 20th century), and several of them are well known. The study of fossil plants was a specialised offshoot; partly botanical, partly geological, but also microscopical. Specimens were relatively easy to obtain, especially if you lived near to coal seams, were a miner, or knew someone working in the coal industry. Amateurs provided the professionals with their raw materials, and the latter relied on them for a regular supply. People such as Professor William C. Williamson, of Owens College, Manchester, were "*garnering a rich harvest from the efforts of these reapers*" (Howell, 2005). The Manchester connection is strong in the development of this topic, and Owens College, founded in 1851 (the forerunner of the University of Manchester), could rightly claim to be at the centre of where Palaeobotany in Britain was established on a scientific basis.

There appears to have been a good working relationship between the amateurs and professionals working on fossil plants. Some of the former went beyond collecting, and prepared thin sections to study the microscopical anatomy of the fossils themselves. From the point of view of the amateurs working on fossil plants, Cash was "*perhaps the best known of the enthusiasts*" (Howell, 2005).

Figure 1. Portrait of William Cash (from Sheppard, 1915).

William Cash

Life and career

There are several obituaries to Cash, including those of Roebuck (1915), Kendall (1918), and Sheppard (1915), which give full details of Cash's life and professional work.

William Cash (Figure 1) was born in Leeds on 28 April 1843. His father, Isaac, was a dyer and his mother, Love Cash (née Brown), died giving birth to William. William had a sister, Mary Hannah (who died before he was born), and also an older brother, John. On the demise of his mother, records relating to his father disappear, and William is thereafter recorded in the household of his mother's brother, William Oddy. William married Sarah Ann Patchett of Halifax at South Parade Wesleyan Chapel in 1866, and they had three children (Mary, Annie, and John Percy). Sarah died in 1896, aged 53. One of Sarah's brothers, George Patchett (1820 -1898), founded a successful wiredrawing business at Sedburgh Mills, Halifax, and his sons became pillars of the local community (Patchett, 2016).

Described as having a "*charming personality*" (Sheppard, 1915) and a "*cheerful and genial optimism*" (Roebuck, 1915), Cash began his career working for the Halifax and Huddersfield Union Banking Company, and later, around 1893, set up independently as an accountant and Insurance and Mortgage Broker in the town. It would appear that shortly before his demise his accountancy practice was in some difficulty, and he retired from business in somewhat straightened circumstances (Kendall, 1918). It may well have been this situation that prompted the disposal of his slide collection, although he frequently sent material and slides to Professor W. C. Williamson and others. He died, aged 71, on 16 December 1914. He was working on the morning of the day he died, for Professor Kendall of Leeds University. The end came the same afternoon, when he fell in the garden after a walk and died, probably from a haemorrhage (Anon., 1914). A very full obituary can be found in the *Halifax Courier* (Anon, 1914).

A man of "*wide knowledge and multifarious activities*" (Roebuck, 1915), which included politics, religion, freemasonry, literature, and languages, it was in science that he was best known. When the geologist Professor Kendall arrived in the north, he was impressed with the amateurs and their work, and none more so than Cash. In his obituary to Cash, Kendall described him as a man "*to possess the widest outlook…deeply imbued with the true spirit of a naturalist as any man I have met*" (Kendall, 1918). In the absence of any specific evidence, it must be assumed that William, who hailed from the poorer echelons of society (William Oddy, his uncle, was a Clothdresser), took full advantage of the numerous night-classes and supported schools of the neighbourhood (as did many of the 'artisan naturalists' of that locale) to gain his scientific education.

One obituary (Anon, 1914) described "*his happy way of imparting* [the] *interest to others*". Cash was a popular and stimulating lecturer, and took great care in his preparation for this work (Kendall, 1918). He travelled to Mexico in 1899, and on his return gave several lectures on his experiences and on the flora and fauna. He also gave talks on fungi, volcanoes, fossils, marine animals, and the natural history of the Channel Islands (Anon, 1914).

Society memberships

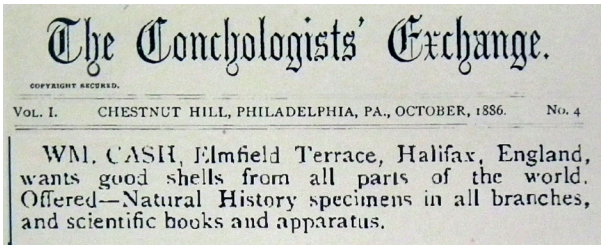
William Cash was very active in local affairs. He was one of the founders and twice President of the Halifax

Scientific Society (Cash, 1897) and President of the Halifax Geology Field Club, Treasurer of the Halifax Literary and Philosophical Society (Sheppard, 1915), and, for a period, governor and honorary curator of the Halifax Museum (Anon., 1914). He also served the Halifax School Board in various capacities (1883-1892), including Chairman (1889) (Sheppard, 1915).

It is difficult to imagine that, in addition to his professional work as a banker and accountant, Cash could be active in so many societies at both local and national level. Apart from the work in his adopted town, Cash was a Fellow of the Linnean Society (1888), Fellow of the Geological Society (1876) and Fellow of the Royal Microscopical Society (1888), Honorary life member of the Yorkshire Naturalists' Union (YNU), and secretary of the YNU Fossil Flora Committee. He was also an Honorary member of the Bradford Natural History Society. In geology, as a member of the Yorkshire Geological Society, he acted in most capacities including being a Council member, editor of the Society's Proceedings, treasurer, and was later a Life Member. He was a member of the British Association for the Advancement of Science (BAAS) from 1873, and submitted reports on several occasions at their meetings in the 1880s (Anon., 1914; Kendall, 1918).

Scientific interests

Cash was, first and foremost, a collector, but he was much more than that. In addition to his expertise in palaeobotany, his main zoological interest was in molluscs (conchology), both fossil and present-day forms, and he started and ended his scientific career publishing papers on this phylum. One example of his interest in shells is an advert he placed in a North American magazine, for shells "*from all parts of the world*" (Figure 2). He was a member of the Leeds Conchological Club and a Life member and one-time President of the Conchological Society of Great Britain. For a period in his life, he also specialised in the Cephalopoda (squid, cuttlefish and octopus).


The Conchologists' Exchange.

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WM. CASH, Elmfield Terrace, Halifax, England, wants good shells from all parts of the world. Offered—Natural History specimens in all branches, and scientific books and apparatus.

Figure 2: Title from The Conchologists' Exchange (October 1886) and the exchange entry of William Cash, from the same edition.

An indication of his broad interest in natural history can be found in his entries in the Exchange columns of *Hardwicke's Science-gossip* (later simply *Science-gossip*), the popular Victorian science magazine. From looking for "*fresh specimens of any Cuttlefish or Squids*" to "*good specimens of local objects of Natural History in every department (animal, vegetable, mineral, and fossil)*", he was also looking for books, and was willing to offer shells, insects, microscope slides, cephalopods, echinoderms, books, and even money in exchange, although the emphasis was on shells (Cook and Taylor, 1865-1893; Carrington, 1894-1902).

The early palaeobotanists

Cutting and grinding to produce thin specimens of rock for viewing under the microscope was a time consuming, difficult, and specialised process, and great care was required to obtain the right thickness: "*Perhaps no branch of Palaeontology presents greater difficulties to the geological student than that of Fossil Botany, and this is especially true of the fossils in the Palaeozoic rocks*" (Cash and Hick, 1878). There was a network of early palaeobotanists, including James Binns, John Butterworth, and James Spencer, who developed and refined preparation techniques.

James Binns

In the 1891 Census, James Binns was recorded as living at 15 Walsh Street, Halifax, Yorkshire, and listed as aged 59, a Stone Dresser, born in Ovenden, Yorkshire. He was married to Grace Binns, aged 51, born Warsley, Yorkshire. They had a boy and two girls, all of whom worked in a Worsted mill. James Binns was a member of the Lancashire and Yorkshire Palaeobotanical Society (founded 1893), and was one of the many amateurs who prepared fossil plant specimens for W. C. Williamson (Howell, 2005).

John Butterworth

John Butterworth, F.R.M.S., was a Corresponding Member of the Manchester Microscopical Society in 1890 and 1891 was living then at Shaw near Oldham. He was still a Corresponding Member in 1896 and 1897-1899, and was then living at 122 Rochdale Road, Shaw, but interestingly the F.R.M.S. is no longer cited. John Butterworth wrote to *Hardwicke's Science Gossip* concerning proposals for a circulating cabinet of slides (Butterworth, 1865). More extensive details of his life and activities have been published via the Internet (Stevenson, 2014).

James Spencer

James Spencer (1834-1898), born in Luddenden, Yorkshire, was interested in the fossil flora of the Halifax Hard Bed Coal Measure, and discovered the club moss *Lepidodendron spenceri* (Williamson, 1878). He was Chairman of the Yorkshire Fossil Flora Committee. Examples of his slides are illustrated below (Figure 3).

Figure 3. Sample slides by James Spencer. Images: D.S. Gill.

Much of the early work in palaeobotany was done by James Spencer, who, before meeting John Butterworth, found it slow and painstaking: "*he had to break the petrified stems of plants out of the hard nodules, then chip thin pieces off with a chisel, then rub them down on the sink-stone until they were so thin light would shine through them. Then they had to be polished and mounted on glass*" (Stevenson, 2014). Butterworth taught Spencer quicker and more scientific ways of preparing slides, and in turn Spencer helped Cash. This network of likeminded individuals - both amateur and professional - worked well, and the amateurs in particular were generous in giving their time in preparation, advice, and borrowing material.

Cash's collaborators

"There was a bevy of working men in the Lancashire-Yorkshire area producing thin sections of fossil plants" (Howell, 2005).

Cash knew many of the amateur and professional botanists and geologists in Lancashire and Yorkshire, and wrote obituaries for several of them, including James William Davis, Thomas Hick, Robert Law, Walter Percy Sladen, and W. C. Williamson. Hick and Williamson were professionals on the staff at Owens College, Manchester. Some of these people, and several others named above, were important in Cash's work.

The eminent Scottish palaeobotanist Robert Kidston also provided a useful source of reference and help. Robert Kidston (1852- 1924) F R S, F.R.S.E., F.G.S. was born in Renfrewshire and based in Stirling. He had close contacts with Scottish university botanists, and had great knowledge of and published widely on Carboniferous plants. An expert photographer and artist, his collection of thin-sections is now housed at the Hunterian Museum, University of Glasgow. The main bulk of his material - the compression floras - resides at the British Geological Survey, Keyworth. Cash's main collaborators are discussed below.

W. C. Williamson

William Crawford Williamson (1816-1895). M.R.C.S. (1840), LL.D. Edin. (1883), F.R.S (1854), the Professor of Natural History at Owens College, Manchester, was born in Scarborough on the 24th November 1816 (he died at Clapham, Surrey 23 June 1895). After an early grounding in natural history from his father, Williamson trained for a career in medicine and, after accepting the appointment of Curator of the Manchester Natural History Society Museum in 1835, practiced medicine for a time in Manchester. Described as the founder of modern palaeobotany, he was the first Professor of Natural History (later surrendering his Zoological duties and becoming Professor of Botany until 1892). Williamson became an expert on fossil plants, publishing extensively in the Philosophical Transactions of the Royal Society (Williamson, 1887, 1880, 1889, 1893), and combined with William Cash to present a paper at the British Association meeting in Manchester in 1887 (Williamson and Cash, 1887): 'On investigating the Carboniferous flora of Halifax and its neighbourhood'. Cash also reported at other British Association meetings in his own right, and also as a member of committee (Cash, 1881; Hick and Cash 1881; Williamson and Cash, 1882; Williamson et al., 1883). Williamson wrote his reminiscences, edited by his wife and published after his death (Williamson, 1896).

Thomas Hick

Thomas Hick (1840-1896) BA, BSc, ALS, was born in Leeds on the 5th May 1840 and died at the home of his son in Laisterdyke, Bradford, on the 31st July 1896. Hick received his academic training in London under Thomas Huxley and William Turner Thiselton-Dyer, and several of Cash's early papers on fossil plants were written with Hick (see Sheppard, 1915). Hick had worked in a mill but, owing to an accident in which

he lost some fingers, he became a schoolmaster and then a headmaster in Leeds, and taught science at a school in Pannal, Harrogate, before Williamson brought him to Manchester. Hick was Assistant Lecturer and Demonstrator in Botany in Williamson's department, and they worked closely together. When Williamson retired, Hick and others (Miles Martineau Buckley, John Butterworth, William Cash, Thomas Hick, James Lomax, Thomas Mitchell, and George Wild) kept the community of palaeobotanists together by forming the Lancashire and Yorkshire Palaeobotanical Society in September 1893. John Butterworth was its first President, and Thomas Hick the Secretary. James Spencer, James Binns, and Isaac Earnshaw joined shortly afterwards. The first meeting of the Society was held at Hick's home in Rusholme (see Howell, 2005).

James Lomax

To an extent, James Robert Lomax (1857-1934) F.R.M.S. was the outsider, driven by commercial interests as well as science. Although he cut sections for Williamson, there was nothing to be gained financially by writing scientific papers, even if he had the ability to do so (Howell, 2005). Finding new species of fossil plants and cutting sections of them was far more profitable, as they brought a good price. Lomax was born at Radcliffe, Bury, and after leaving school, worked at Elton collieries, where his father was manager. Working at other collieries in different capacities for many years, his interest in geology was aroused by the fossil plant remains found in the mines. He became skilled in microscopy, producing high quality rock sections and, encouraged by W. C. Williamson, for whom he prepared slides, he later became a full-time commercial manufacturer, firstly in his home and then in premises under the title 'The Lomax Palaeobotanical Laboratories' (Bracegirdle, 1998), and later as the 'Lomax Palaeobotanical Company' in Bolton. Bracegirdle (1998) states that Lomax's slides are "*now much sought-after*".

The following illustration shows some of the slides made by him (Figure 4). He collected and prepared material for teaching, research, museums, and private collections, and pioneered new techniques for preparing slides. However, many of these are of limited use scientifically as the known examples are often inadequately labelled. Also, serial sections are required when studying anatomical features, and these were often unavailable (Howell, 2005). Cash produced one paper with Lomax (Cash and Lomax, 1890).

Figure 4. Examples of slides by Lomax under the auspices of the Petrographic and Palaeo Botanical Laboratories Images: D.S. Gill.

The Coal Measures and their fossil plants

At the time of the coal measures (late Carboniferous Period, circa 300 million years ago), there were dense forests growing on low-lying swampy ground, with raised banks providing drier ground. As plants died, they partially decomposed in the wet, anaerobic conditions of the swamps. As they were compressed over time, water, oxygen, and hydrogen were slowly removed, producing coal deposits containing fossilised plant remains. (West Yorkshire Geology Trust, n.d.; Natural History Museum, n.d.).

There were no flowering plants in the late Carboniferous Period, and many of the plants that lived at this time are now extinct. The dominant plants were the club mosses (Lycopodiales) including the closely-related *Lepidodendron* (scale tree) and *Sigillaria*, together with *Calamites* (a genus of horsetails), medullosaleans and lyginopteridaleans (seed-plants), and occasionally ferns. *Lepidodendron* was to become an important fossil plant in the studies made by Cash, and he worked with both Thomas Hick (Hick & Cash, 1889) and James Lomax (Cash and Lomax, 1890) on the anatomy and histology of this plant. The quality of their microscope slides is apparent as they were able to describe in detail the anatomy of the stem, root, cortex, leaves, and fruits. For this work, Hick and Cash wrote that "*we have been greatly indebted to Messrs Spencer, Binns and Lomax, who have kindly allowed us to examine their specimens of Lepidodendron and to compare them with those in our own cabinets*" (Hick and Cash, 1889). Their work clearly relied on the preparations of others. They were borrowing and obtaining slides from several sources all the time and refining their understanding of the plants with each specimen. For example, Hick and Cash (1884) described the vascular bundles, cambium, and cortex of the horsetail

Calamites from "*a species* [that] *has come into our hands which presents a more perfect view of the transverse section of a Calamite than we have previously met with*".

Cash published a paper in 1906 which is full of practical advice on fossil plants, their collection and preservation, the naming of species, notes for guidance in dealing with them, and the strata in which they are found. Full and correct documentation and labelling of the specimens is emphasised, and he recommended suitable literature. However, a distinction is made here between collecting, documenting and describing fossil plants obtained from field work (Cash, 1906), and laboratory work examining their detailed internal anatomy and histology by means of microscopy (Hick and Cash, 1884; Hick and Cash, 1889).

Cash eventually became an expert on The Halifax Coal Measure fossil flora, and published several works on this bed. He found and described several specimens that were new, but some of the more important ones were described by W. C. Williamson. Cash worked with Hick on fossil fungi (Cash and Hick, 1879). Some of the slides from the Cash Collection held at Manchester Museum are illustrated below (Figure 5). A full list of Cash's publications (1877 to 1912) is given at the end of Sheppard's (1915) obituary, and reproduced in Appendix I.

Collections

There over 700 of Cash's collection of microscope slides at the Manchester Museum, referred to as the Cash Collection, and these have been scanned and catalogued (Gelsthorpe, 2016). The collection includes mounted specimens by James Binns, J. P. Cash, James Spencer, and Frederick Ernst Weiss. Cash also presented many valuable specimens to other museums, including institutions in London, Edinburgh, and Bradford.

Bradford Museums and Galleries purchased Cash's Carboniferous Coal Measures fossils (79 specimens in all) for £2-2-0 in 1913, a year before Cash died. They have an accession date of 31 May 1913 (City of Bradford Corporation, 1913). Some of the fossil plants are from Moncton Main Colliery (Barnsley), Darfield Quarry and Church Lane colliery near Dodworth (McGowan, 2016). Bradford Museums and Galleries also have echinoderm material attributed to Cash.

Figure 5. Coal Sections from the Cash Collection of Manchester Museum.
Q514 (1st left): Stigmaria sp. Lycopsida. Carboniferous Coal Measures "Oldham"
Q515 (2nd Left): Stigmaria sp. Lycopsida. Carboniferous Coal Measures "Dulesgate"
Q519 (3rd left): Stigmaria sp. Lycopsida. Carboniferous Coal Measures "Halifax Hard Bed"
Q518 (right): Stigmaria sp. Lycopsida. Carboniferous Coal Measures "Head of sporangiophore Cal. Binna?" "Halifax Hard Bed"
Images: Manchester Museum, University of Manchester (reproduced with permission).

Hartley et al. (1987) lists museums in Yorkshire which hold Cash documents and material. Bolton Museum houses material either purchased from or donated by James Lomax (Stenhouse, 2016).

W. C. Williamson's fossil plant microscope slides are in the Natural History Museum in London. Thomas Hick's fossil plants and slides are held at Manchester Museum (Cash, 1896).

Discussion and conclusions

In terms of plant fossils from the Coal Measures in the North of England, William Cash was an important figure and made a significant contribution. He had good links and working relationships with both the amateur naturalists and the relevant professional biologists at Owens College, Manchester. He published widely on the subject and these papers, plus his collections, are his legacy.

Acknowledgements

Thanks are due to David Gelsthorpe of Manchester Museum for help with the Cash Collection, housed therein. Gerard McGowan at Bradford Museums and Galleries, Don Stenhouse at Bolton Museum and John Patchett from West Yorkshire (Calderdale) Archives at Halifax, all provided useful additional information which the authors are pleased to acknowledge.

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Wrestling with the Yatiantota Tusker: Cleaning, conserving and mounting an intriguing Asian elephant skeleton

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Abstract

Cambridge University Museum of Zoology underwent refurbishment between 2013 and 2017 as part of a wider redevelopment project. As well as cleaning and conserving the specimens that were already on display, the opportunity was taken to conserve, remount and re-display some specimens from the collections that had been in storage for years. The most significant and problematic of these was the skeleton of a large male Asian elephant. The specimen has an interesting history, having killed many people in Sri Lanka before being shot in 1881, and in the 1960s the skeleton was used as set-dressing for an iconic science fiction film. The bones were successfully cleaned using Synperonic A7 in deionised water, with acetone added as required for the grimiest areas. The metalwork for the skeleton had been missing for decades, so a new mount had to be made from scratch. This involved a variety of skills, including blacksmithing, welding and engineering processes, and therefore had to be undertaken offsite in a suitably large conservation facility, involving transporting the skeleton by road. The Asian elephant skeleton is now back on display next to the skeleton of the African elephant, so that they can be compared. The skeleton exhibits very obvious pathological deformation in many of the bones, providing a particularly engaging exhibit.

Keywords: Elephas maximus; Osteology; Rogue; Pathology; 2001 Space Odyssey

Introduction

Cambridge University Museum of Zoology underwent refurbishment between 2013 and 2017 as part of a wider redevelopment project. The six-storey 1960s Arup Building in which the museum was located required complete refurbishment, after which the rest of building would form part of the 'Cambridge Conservation Initiative'; a unique collaboration between the University of Cambridge and the Cambridge-based cluster of leading biodiversity conservation organisations. The incidental and unavoidable complete refurbishment of the University's Museum of Zoology meant that exciting new displays could be planned, as well as the re-interpretation of old specimens and the display of some material that had not been on show for a while, or had never been displayed before. The skeleton of a large male Asian elephant (*Elephas maximus* Linnaeus, 1758; UMZC.H.4611) had been on display in the old museum from 1865 to 1965, but had lain in storage

for almost 50 years. The redevelopment project seemed an ideal opportunity to put the Asian elephant skeleton back on display alongside the African elephant skeleton (*Loxodonta africana* (Blumenbach, 1797); UMZC. H.4451), similar to how they had been displayed in the past (Figure 1).

History of the specimen

The Asian elephant skeleton had last been seen by the public when it was used as set dressing for iconic scenes in the 1968 epic science fiction film *2001: A Space Odyssey* by Stanley Kubrick and Arthur C. Clarke (Lowe, 2014). Early on in the film, when primates are seen living in an African landscape, many of the bones scattered around the set are from this particular elephant skeleton.

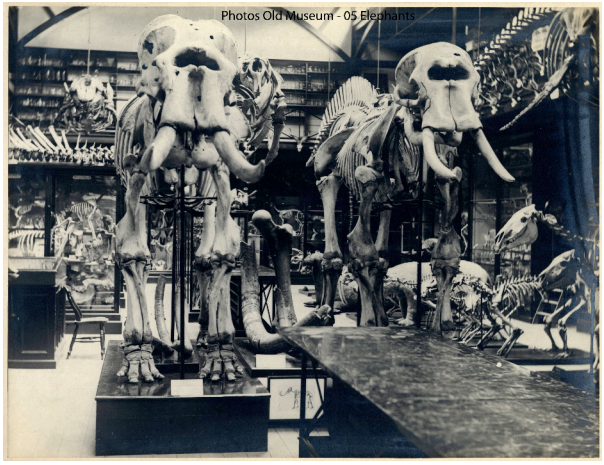

Figure. 1. The two elephant skeletons on display in the 'Old Zoology Museum' at Cambridge University. The Asian elephant (UMZC.H.4611) on the left, the African elephant (UMZC.H.4451) on the right. Image: Cambridge University Museum of Zoology.

The specimen has another claim to fame, however. The elephant was shot in 1881, as it was damaging crops and killing people in Ceylon (now Sri Lanka). The only information the museum held about the specimen was the transcription (Shipley, 2011) of an entry made in a notebook by the controversial civil servant (Powell, 2010) C.J.R. Le Mesurier, who was sent to shoot the elephant:

"*The Yatiantota Tusker, a notorious and proscribed rogue elephant (bull), that had done much damage to life and property. It was shot on 6th February 1881, at Yakkela Kele ("forest of the devil's stream"), near Malalpola, eight miles from Ruanwela, in the Kegalle district, Western Province, Ceylon. Height, 9 feet; tusks, 4 feet 11½ inches, and 4 feet 10 inches outside curve - weight 75lbs.*" (Shipley, 2011: p.281)

With the exception of the tusks, which were retained as a trophy, the elephant skeleton was presented to the Museum of Zoology in 1882 by Sir John Phear MA, Chief Justice of Ceylon, after being prepared and packed by the taxidermist of the Colombo Museum (Shipley, 2011).

At the Natural Sciences Collections Association (NatSCA) conference in 2017, themed 'Provocative new ways of working with collections', Subhadra Das (UCL Culture) and Miranda Lowe (Natural History Museum, London) presented a thought-provoking talk titled '*Nature read in black and white; or, How to stop being racist and develop worthwhile natural history curation*'. They pointed out that a significant proportion of specimens in natural history collections in British museums had been collected during the time of the British Empire. Methods of acquisition were varied but many would have directly reflected aspects of colonisation or even slavery. However, such histories are rarely explored in museum narratives, which mostly focus on scientific discovery and advancement. Das and Lowe suggested that, by giving such specimens a purely scientific interpretation, museums were not only ignoring an important part of each specimen's context but were effectively creating barriers to source or diaspora communities, potentially leading to the alienation of these communities from museums. They recommended that one way to improve understanding of the context in which specimens were acquired would be for natural science curators to engage historians specialising in the relevant time period, preferably those indigenous to the geographical area under discussion, to assist with creating an appropriate narrative for the display (Das and Lowe, 2017).

However, attempting to recover information about a specific specimen – even one as notorious as this elephant - after such a long period of time has elapsed is not necessarily straightforward or successful. Several members of staff at the Natural History Museum in Sri Lanka were contacted to ask if any contemporary accounts or other information relating to the murderous 'Yatiantota Tusker' existed but, despite repeated attempts at contact, no response was received. Reports from the time might have told us who had been injured or killed by the elephant, giving names to replace the vague "*much damage to life and property*". The perspective of families left behind after these encounters would have given invaluable context. Not least because now, over 100 years later, between 30 and 50 people

a year are killed by elephants in Sri Lanka due to increases in the human population and subsequent changes to land use patterns, reducing the natural elephant habitat and inevitably generating conflict (Bandara and Tisdell, 2002; Santiapillai et al., 2010).

Extensive searching on the internet uncovered a little more detail about the Yatiantota Tusker, found in a scanned version of an out of print book from 1894 that has only been available online since 2007. Typically, it is from the perspective of a British trophy hunter, but these few words themselves are telling, as it may be that the rogue was killed as much for its unusually large tusks (almost 5 feet in length) as to stop it from killing indigenous people. At least this account puts a minimum number on the victims:

"*The Ceylon elephants have no tusks, the bulls sometimes developing tusks about a foot long. During a seven years' residence in Ceylon I never heard of but one tusker, the celebrated Yatiantota rogue, which was killed by two friends of mine after a struggle lasting many hours. During his career this elephant had certainly killed a score of human beings. His appearance may be familiar to the reader as his fore-part, beautifully mounted by Ward, formed the central object in the Ceylon Court at the Indian and Colonial Exhibition*." (Snaffle, 1894: p.174-175)

Upon examining the skeleton, one possible reason why this animal was dangerous becomes clear: its left ulna seems to have been broken at some point during the animal's lifetime, and it certainly became badly infected, fusing to the radius. The consequent severe pathological deformation of the bone is very obvious (Figure 2). The animal would clearly have been disabled and in pain. Other, possibly associated, pathologies in the skeleton are also obvious: the symphysis of the mandible swells distally and is porous and asymmetrical, which is abnormal (Figure 3); there are also abnormal bone growths on the proximal end of the left humerus and in the first left rib, and in the left scapula; and some of the vertebrae are asymmetrical, with bony overgrowths clearly visible ventral to two vertebrae (Figure 4). The fact that this animal was suffering from what must have been a painful and debilitating injury and then subsequent disease may well have led it to become a dangerous 'rogue' elephant, apparently killing at least 20 people.

Cleaning, conserving and mounting the skeleton

The skeleton was dirty from being in storage for 50 years, most recently laying uncovered on open racking. Many bone surfaces were sticky with residues of natural oil, and therefore dust and dirt had adhered to these areas, turning them black over time.

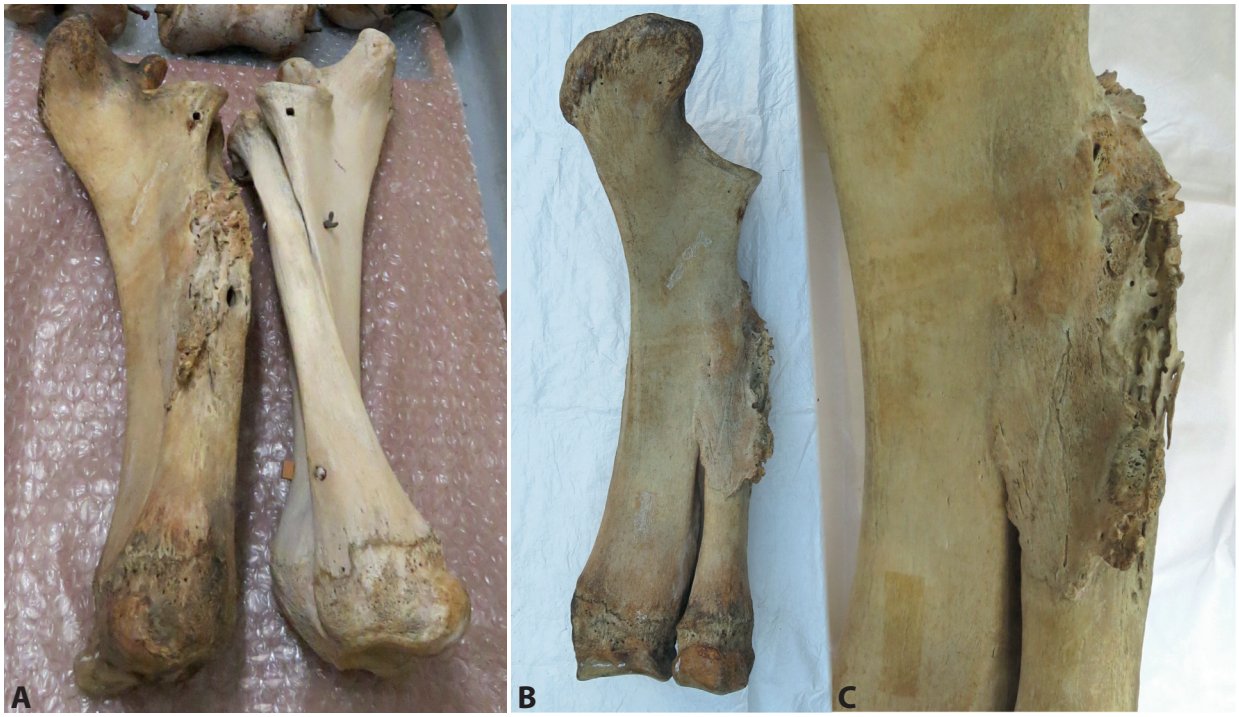

Figure 2. A. The radius and ulna of both of the forelimbs of UMZC.H.4611, showing the pathologically deformed left radius and ulna to the left of the image clearly different to the right radius and ulna on the right of the image; B. the fused left radius and ulna, showing the area of deformed bone; C. a close-up of the diseased area of the left ulna. Image: Nigel Larkin.

Figure 3. The pathologically deformed symphysis of the mandible of UMZC.H.4611. Image: Nigel Larkin.

Figure 4. Pathologically deformed vertebrae of the Asian elephant skeleton (UMZC.H.4611): two asymmetrical vertebrae and on the far right a vertebra with a bony overgrowth ventral to the centrum. Image: Nigel Larkin.

This dirt had to be removed along with chalk marks, small splatters of paint, and scuff marks from the movement and storage of the specimen over time (Figure 5). None of the original metal mount survived the loan to MGM studios in 1967, except the bar on which the vertebrae were threaded and some of the small brackets that held the limb bones together. Therefore, the skeleton had to be mounted from scratch with a new purpose-made metal armature. As the specimen was of historical significance, where possible it was mounted in the same way as before, so that old holes drilled into the bones could be reused, rather than drilling new holes in the specimen. Unfortunately, only a single photo was available of the skeleton mounted in the old museum, and little of the original mount could be observed. Therefore, the mount of the African elephant skeleton on display was used as a guide. All conservation and cleaning techniques and materials used during the project were as minimally invasive as possible. Adhesives and consolidants used were stable and reversible, and all processes and materials used were recorded.

Cleaning

The bones were cleaned first with dry soft brushes next to the hose of a vacuum cleaner (covered with gauze) to remove the loose debris and dust. Ingrained deposits were cleaned with Synperonic A7 in deionised water. Synperonic A7 is an alcohol ethoxylate, a mild non-ionic detergent. Synperonic has been widely used by conservators in museums for decades as a standard conservation product to clean particularly dirty osteological specimens and other material. It can be used as a detergent, wetting agent, non-ionic surfactant, and an emulsifying and dispersing agent (Hackney et al., 1990; McCutcheon's, 2003).

A 2% solution of Synperonic A7 in deionised water was applied to small areas of bone at a time with a soft brush, then wiped away immediately with a lint-free paper towel. The area was then brushed with deionised water and immediately dried again with a paper towel, and this 'rinsing' was repeated immediately a second time. It was important not to let the areas dry out completely between applications, to avoid repeated cycles of wetting and drying. The dirtiest areas, particularly the patches of black, greasy bone, were cleaned in a similar fashion but with acetone added (1 part acetone to 3 parts Synperonic A7 solution), applied with stiffer brushes.

Whilst dry methods of cleaning bone (such as smoke sponges and 'groom sticks' made of natural rubber and air) are less invasive than wet methods, they may not clean a specimen as effectively, especially if the bone surfaces are rough, like those of an elephant bone. There is a small element of risk to the process: even though the area cleaned is 'rinsed' with deionised water a couple of times immediately after applying the detergent, there is no guarantee that the detergent will be entirely removed. Also, multiple applications of water over a period of time can damage molecular bonds within bone and ultimately exacerbate deterioration. However, a wet cleaning

Figure 5. Examples of how dirty the bones of UMZC.H.4611 were before cleaning A. Paint and chalk marks etc on very dirty limb bones. B. A humerus mostly cleaned but the lower left section still dirty. Image: Nigel Larkin.

treatment is rarely required, and should be limited only to specimens that are extremely dirty.

Old temporary labels made from 'sticking plaster' roll (as used in first aid) stating 'left humerus' or 'right scapula' etc, from when the skeleton had been dismantled in the 1960s, were removed gently with a scalpel, as they were redundant. Where small breaks in bones had been repaired in the past, some excess adhesive (possibly protein colloid 'animal glue') had spilled out onto the surfaces of the surrounding bone. This was unsightly and was easily removed with scalpels. The glue within the breaks was stable and did not require removing and replacing. In many places, a white waxy substance was lying on the surface of the bone in patches, ranging in depth from a paper-thin film to a thick deposit up to 4 or 5mm deep, particularly on the skull. This was largely removed with thin wooden spatulas and stiff brushes, before final cleaning with Synperonic A7. The substance remains unidentified, but it is possible that it was a temporary water-soluble putty such as that sometimes used when preparing a specimen for moulding (Rixon, 1976), although there is no record or recollection of the skull or other bones having been replicated. When the skeleton was being used during the filming of *2001: A Space Odyssey* at MGM studios in 1967, almost all of the metal mount was lost. It is possible that the bones were interfered with whilst on loan, and this waxy substance may date to this period.

Although all the bones have been cleaned, they are not a uniform colour. They have a natural variation, but also the lower right forelimb (foot, radius and ulna) is much lighter in colour than the rest of the skeleton (Figure 2), despite all the cleaning undertaken on the other bones. This forelimb was on display in the museum from the 1970s until 2013, and whilst it is possible that the bones had been artificially whitened for display, there are no records of this process. A more likely explanation is that the bone colour faded over time due to the lighting conditions (Cassman et al., 2006). Several other specimens on display in the museum during this time suffered the same fate. The rest of the elephant skeleton could be treated to make the bones lighter to match the right forelimb, but this would have been an unnecessary, and potentially damaging, invasive procedure. In the past, chlorine bleach has been used to whiten skeletons, even though this can degrade the structure of bone long after the treatment (Mori, 1979; Fenton et al., 2003). Hydrogen peroxide has also been used and, whilst this is less deleterious than chlorine bleach, it is still an invasive and potentially damaging process.

Conservation and mounting

The new metal mount had to be designed and made in a way that would allow the specimen to be fully mounted in the author's conservation studio in Shropshire and then disassembled and transported safely to the museum in Cambridge, where it would be assembled again. As the specimen's permanent display position would be on top of a wheeled plinth about 1m high, which would need to be moved occasionally, the skeleton's metal mount needed to be particularly strong, rigid, and secure.

The metal bar that the vertebrae had been stored on for at least the last 50 years was the only substantial piece of the original mount that survived the loan to MGM Studios for filming. This bar is T-shaped in cross-section and runs through the neural arch of each vertebra. It was thick with rust and bent at one end, presumably from poor handling. However, as the rust was easily removed with a flap-disk of sandpaper on an angle grinder and the bar could be straightened after heating on a forge, there was no need to replace it. It had rusted simply because it had never been painted. This metal bar and all other new metalwork was painted to prevent rust forming, using 'Ivory' coloured acrylic aerosol spray for metals with a matt finish, to match the colour of the bones.

A separate, thin metal rod ran the length of the spine through a small hole in each of the vertebral centra. This had rusted and was stuck firmly within the bones (Figure 6). This rod had to be cut into sections between the vertebrae so that the bones could be slid off the main vertebral bar one by one, after which the pieces of rusty rod could be removed. The thin rod was replaced with a new steel rod that was heated and bent to the curvature of the spine. It was slightly thinner than the original, to ensure it would slide through the holes in the vertebrae more easily.

In the single old photograph that shows the skeleton as it was previously mounted (Figure 1), it can be seen that only two upright supports were used, one under the pelvis and one under the neck. The skull would have been inserted onto the end of the vertebral bar via the foramen magnum, with a hook attaching the rear of the skull to the atlas vertebra. However, there are severe cracks in the rear of the skull around the occipital foramen (Figure 7). This area would have taken the strain of the weight of the skull, mandible, and tusks in its previous mounted position, and it

seems to have suffered damage as a result. The cracks in the skull were not treated, as there was no loose material, and filling the cracks would have been merely cosmetic. The integrity of the rear of the skull had been compromised, and it therefore could not be mounted in the same way without suffering further damage. For this reason, and because the skeleton would need to be moved around the gallery occasionally on the plinth without swaying, a third upright support was required specifically to take the weight of the skull, mandible, and tusks from below.

Three steel tubes (22 mm internal diameter) were cut to fit i) under the pelvis, ii) between the front legs, and iii) underneath the skull. Each of these was a different height. A section of threaded steel bar (22 mm diameter) was inserted into each of the lower sections of these tubes, protruding by several inches, and was MIG (Metal Inert Gas) welded into place at the end of the tube. A steel 'floor plate' was then welded to the base of each tube to form a collar that would sit on the top of the wooden plinth (Figure 8), with four holes in the horizontal surface so that it could be screwed to the top of the plinth. The threaded bar in the lower end of each tube inserted into a hole drilled through the plinth under the pelvis, pectoral girdle, and skull, in line with the vertebral bar. On the underside of the plinth, these threaded bars inserted through a large, flat steel bracket, designed to reduce the ability of the upright poles to lean sideways. The threaded bar was secured on the other side of this bracket with nuts and spring washers. This provided three very secure, robust upright vertical supports to take the weight of the vertebrae, ribs, skull, tusks, mandible, and humeri. A long, thin, steel bracket was made to hold the rear and middle upright tubes together, shaped to fit the contour of the underside of the vertebrae.

By heating and shaping lengths of flat steel bar on a forge and welding them together on top of a short steel rod, a bespoke bracket was made to fit the underside of the sacral block and adjoining vertebrae, so that the pelvis was held comfortably on top of the rear upright tube, with the vertical length of rod inserting into the top of the upright tube (Figure 9). A bracket was made in a similar fashion to hold the cervical vertebrae in place on top of the middle pole. A more substantial steel bracket was made to securely hold the skull in place, so that most of the weight of the skull was held by flat steel under the palate, with small brackets either side of the rear of the skull to stop sideways movement, and the hook on the back of the skull connecting to the vertebral bar. All the brackets were lined with white Plastazote foam, a chemically inert, low density, closed cell, cross-linked polyethylene foam of archival quality (Garside and Hanson, 2011), so that none of the bones were sitting directly on metal.

Five of the eight small brackets that hold the lower limb bones to the upper limb bones were missing, and had to be made using a forge, anvil, hammers, and angle grinder (Figure 10). Some of the threaded

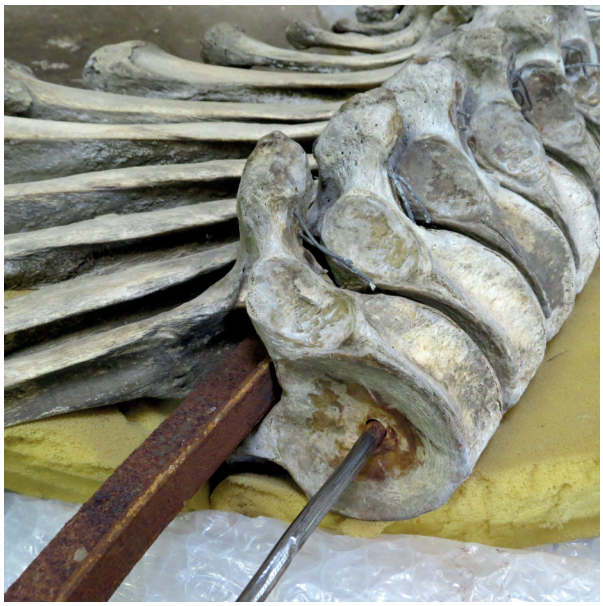

Figure 6. The rusty T-shaped vertebral bar with some of the vertebrae still attached. The thin vertebral rod has been cleaned in an attempt to remove it from the vertebral centra. Image: Nigel Larkin.

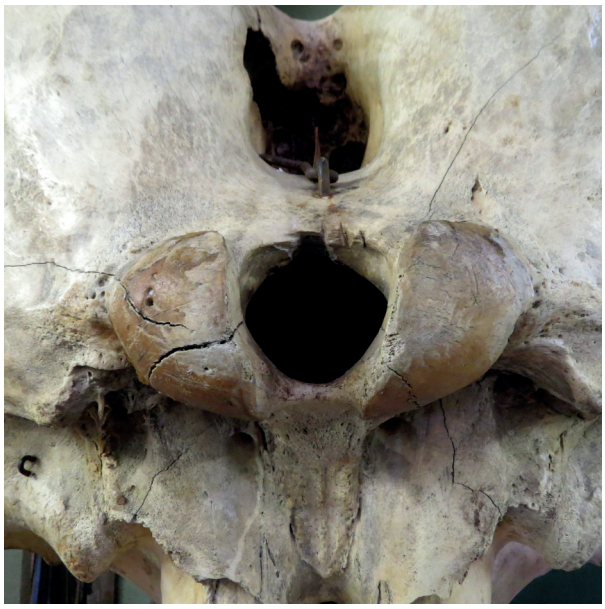

Figure 7. The rear of the elephant skull (UMZC.H.4611) showing substantial cracks around the occipital condyles that have left the skull weak and vulnerable to further damage. Image: Nigel Larkin.

Figure 8. A steel floor plate welded to the bottom of one of the upright steel tubular supports, within which a 22mm diameter threaded bar is welded. This bar runs through the wooden base and is secured underneath with nuts and spring washers. Image: Nigel Larkin.

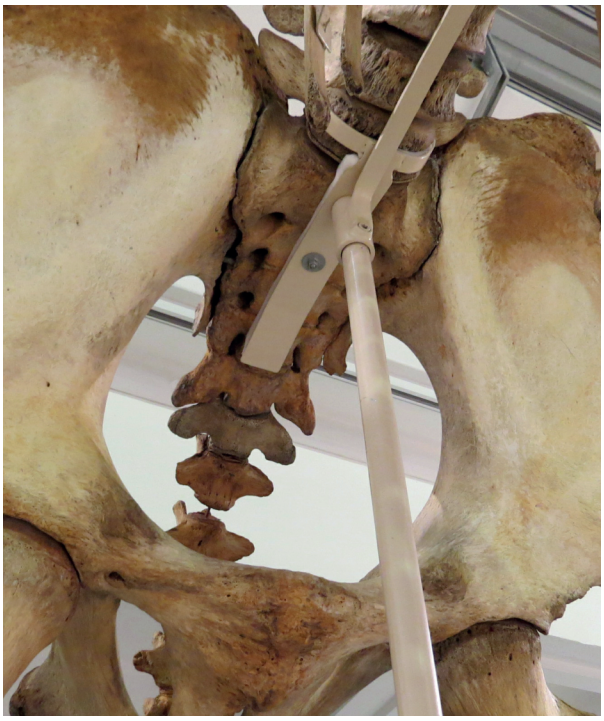

Figure 9. The steel support for pelvic region: the vertical rod on the underside inserted into the top of the rear upright support; and the upper surfaces of the metal bracket are lined with white inert Plastazote foam under the bones. Image: Nigel Larkin.

bars that had been inserted into the ends of the limb bones for attachment to the brackets were missing, and some were present but bent. Therefore, some had to be bent back into position and others replaced.

A horizontal steel rod with a threaded bar welded to either end was made to hold the humeri in position, using the existing wide holes running through the shaft of each bone that had held the previous supports. This rod was attached to the middle upright support with nuts and bolts running through a small, flat plate that was welded to the horizontal bar, securing it to a bracket on the upright tube. The bracket was held in place with a grub screw secured with an Allen key.

Some of the small pieces of original metalwork were very difficult to remove. The bracket on the underside of the mandible was very rusty and needed to be removed for cleaning. The bolts securing the bracket could not be undone, even after WD40 had been carefully applied to the metalwork a few times. Therefore, a small 'pen'-sized blowtorch was used to heat and expand the rusty metal bracket and un-seize it from the bolts, which could then be unscrewed and removed. The bracket and the bolts were cleaned with wire brushes to remove the rust, and were then painted to match the rest of the metalwork and bones.

Many toe bones were loose and not attached to the otherwise articulated feet. These loose bones had to be identified and re-attached using thin wire (0.8 mm diameter galvanised steel) running through the old holes. Some old, rusty wires holding foot bones together were brittle and had to be replaced. A support was made for each foot, to replace the missing metalwork, consisting of an upright steel tube welded to a steel base plate that could be screwed to the top of the plinth (Figure 11). The metal rod of the bracket for the rear of each foot could then slide into the top of the tube to hold the foot in the correct, upright position.

The strips of cartilage from the sternum and from the distal ends of the ribs had dried and curled up at some point in the past. Despite cleaning with Synperonic A7 followed by experimenting with soaking a few pieces in deionised water for up to two weeks, these could not be straightened. Fortunately,

Figure 10. One of the five brackets made on the forge to hold the lower limb bones in articulation with the upper limb bones. Image: Nigel Larkin.

Figure 11. One of the four supports made for the feet: a steel tube welded to a base plate with screw holes, so it can be secured to the wooden base. Image: Nigel Larkin.

the anterior-most pieces were not too curled, and this enabled most of the sternum bones to be re-attached with the appropriate pieces of cartilage in place, using thin steel wire running through the old holes.

The ribs were reattached to the vertebrae with galvanised steel wire running through the old holes in the rib heads and vertebrae, with the ends of the wires twisted together on the undersides of the ribs. The ribs were secured in place near their distal ends to one long thin strip of steel on each side, bent to the shape of the ribcage. Where possible, old wire holes were used to attach the ribs to the metal strip, but in some instances new holes did need to be drilled. These were the only new holes required in the whole mounting process.

Four ribs that had been broken historically required repair. This was undertaken with Paraloid B72 adhesive, after the edges of the breaks were consolidated with 10% Paraloid B72 solution in acetone. In two instances, plaster of Paris was used to fill gaps where bone was partially missing. Plaster should never be applied directly to bone, and in this instance the Paraloid B72 consolidant that had already been applied formed a barrier layer that also made the edges of the break more secure, providing a better purchase for the plaster. The plaster was painted with artists' acrylic paints to almost, but not quite, match the bone, as a curator, conservator, or researcher will need to be able to see the change in materials.

The two tusks were replicas of the originals, cast in solid plaster when the animal was defleshed circa 1881, and the originals were retained in Sri Lanka as a trophy. Museum records relate that the real tusks of this specimen became available in 1904, but the 180 guinea (£189) asking price was deemed too expensive at the time (Clark, 1904; Le Mesurier 1904). The solid plaster casts of the tusks were stored separately from the skull, and would have added substantially to the weight of the skull once mounted, pulling the front of the skeleton forward. Therefore, the plaster tusks were moulded in silicone rubber to enable lighter, hollow replicas to be made. Many different resins could have been used to make the replicas of the tusks, but Jesmonite acrylic resin was used with fibreglass because, although it can be heavy, it is very strong and could be worked to create details that were missing on the rather blank and unconvincing plaster casts. Also, Jesmonite is easily painted with artists' acrylic paints to good effect.

Replicating the two tusks saved 22kg in total, and they look more realistic than the original plaster casts.

Transport and installation

After the cleaned and conserved skeleton had been fully mounted on its new metal supports in the conservation studio, it was completely dismantled with the exception of the vertebrae and ribcage. Unwiring all the ribs at either end and then wiring them up again in Cambridge would not only have been an unnecessary amount of work, but it would have placed a lot of physical strain on the ribs, particularly the repaired ribs, which are very vulnerable to breakage during handling. Instead, a supporting frame was built around the ribcage using wooden batons, metal brackets, and a central, sturdy beam from which the vertebral column and associated ribcage hung, held in place in all directions with wide cotton slings (Larkin, 2016). The supporting metalwork could then be dismantled, and any remaining bare metal was painted. All the bones and metalwork were packed in acid-free tissue and bubble wrap. The whole skeleton was transported in a single Luton van. The frame holding the ribcage was placed on a foam mattress and secured to the sides and floor of the van with wooden batons, metal brackets and screws. The skull, mandible, tusks, and limb bones were wrapped in acid-free tissue and bubble wrap, and lay on top of foam mattress. They were securely wedged in place with more foam and bubble wrap to prevent movement.

Once at the Museum of Zoology, the skeleton had to be carried downstairs to the lower gallery one element at a time. Carrying specimens up or down stairs should always be avoided wherever possible, but the lifts were refurbished as part of the overall project and, due to overrunning schedules, were yet to be fully commissioned. It took four strong people to carry the ribcage downstairs, carefully manoeuvring it around the corners of the landings. Installing the skeleton on the 1 m high display plinth posed problems. It had been difficult enough putting the skeleton together in the conservation studio, where hoists were used, but there were no hoists available in the museum gallery. The tops of the three upright supporting metal tubes on which the vertebral column and skull had to be positioned were now about 10 feet from the floor. Although a couple of museum 'stackers' (manually operated fork lift trucks used for moving specimens in museum stores) were available, they did not reach high enough to facilitate getting the vertebral column and ribcage in place. Therefore, the wooden base for the specimen was taken off the display plinth and put back on to the floor, and the ribcage was manoeuvred into position using the two stackers to lift either end of the metalwork. Once the ribcage was secured to the upright supports, the stackers were lowered and used to pick up the wooden base at either end. The wooden base, with the metal supports and ribcage in place, was then raised just above the display plinth and carefully slid into position. All the limb bones were mounted to provide stability to the skeleton before the skull was mounted. To undertake this, surplus wooden crates were covered with Plastazote foam and carefully secured to the stacker platform to make up the height required to get the heavy skull into position. The skull was lifted manually onto the crates on the stacker, and was secured in place temporarily with straps. It was lifted into position and secured on its supporting mount with its original metal hook. Once the skull was secure, the mandible, tusks, and tail were secured in place (Figure 12). The murderous 'Yatiantota Tusker', the "*notorious and proscribed rogue*" once more dominated the museum.

Figure 12. The Asian elephant skeleton (UMZC.H.4611 installed on the high plinth, in the gallery still undergoing refurbishment. Image: Nigel Larkin.

Conclusions

Cleaning the very dirty bones was successfully undertaken using Synperonic A7, with acetone as required. The work could not have been undertaken without using a very large conservation studio facility where hoists could be deployed. Blacksmithing, welding, and engineering skills were essential, as well as a knowledge of anatomy and osteological

conservation. Whilst all the elements of this large skeleton were transported by road some distance to the conservation studio and back, and required a great deal of manual handling when being cleaned and mounted, not a single piece was damaged. The cleaning, conservation, and mounting of the bones, including replicating the tusks and installing the skeleton in the gallery, took approximately four months' work in total.

To have an Asian elephant on display next to an African elephant skeleton is a fantastic and educational sight, enabling direct comparison between the two species, and is entirely in keeping with the history of this museum. That the Asian elephant skeleton has such an interesting history - from disability and disease through the ensuing murderous incidents to appearing in a classic cult science fiction film - is unusual, and this can be explored in many ways, engaging different demographics. In particular, the pathological deformation evident in the bones is sure to fascinate visitors for generations to come. As it currently stands, however, the story of the collection of this particular specimen is typical of such events during the British Empire: despite at least 20 people apparently being killed by the animal, this barely warrants a mention in either of the two contemporary sources. Both accounts focused on the size of the animal and the trophy-worthiness of the tusks rather than on the lives that had been lost.

It is clear that the sometimes-uncomfortable story of how and why many natural history specimens were collected during the time of the British Empire is underreported in museum displays. This can be partly due to the lack of detailed information in museum records, rather than a deliberate curatorial choice. However, the lack of detail can be an interesting story in itself, highlighting the preoccupations and prejudices of the time. As more old and rare books and journals are scanned and uploaded to the internet, information about individual specimens or the collectors involved becomes more readily available. Working with historians and relevant colleagues overseas in the areas from which specimens were sourced should further improve information on historical context, and some interesting stories will no doubt be uncovered in the process.

Acknowledgements

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Mastodon and on and on…A moving story

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Abstract

This is the latest chapter in the history of the mastodon *(Mammut americanum* (Kerr, 1792)) specimen on display at the Natural History Museum (NHM) in London (UK), and continues from the story told by Lindsay (1991). The specimen was selected to be one of the new exhibits for the Wonder Bays of the refurbished Hintze Hall, at the heart of the Waterhouse building. Residing, until recently, on open display in a different exhibition space, the mastodon required stabilisation and careful dismantling before transportation and re-assembly in its new site.

Keywords: Butvar B98, Fossil, Conservation, Specimen move

Specimen History

The mastodon bones *(Mammut americanum* (Kerr, 1792); NHMUK PV OR 15913) were excavated in 1840 in Missouri, USA. Albert Koch, a self-confessed 'fossil showman', purchased the bones and created a large skeleton, considered at the time to be a biblical aquatic Leviathan. Koch toured it throughout North America and Europe. The specimen was purchased by the NHM in 1844, and was rearticulated by Richard Owen to be more anatomically accurate. The specimen spent several decades in the museum's Fossil Mammals gallery until it was moved to the Mammal Hall in the late 1980s. Its fascinating early history and first gallery move are fully documented by Lindsay (1991). As part of this move, it was stabilised through consolidation with polyvinyl acetate emulsion in water by spraying and drip filling. Broken porous areas were stabilised with Alvar 1570 (polyvinyl acetal) in organic solvents. Cracks were filled with a mixture of alvar, jute flock and kaolin (AJK dough) (Lindsay, 1991), whilst the fragmentary skull and maxilla were replaced with a cast constructed of expanded polyester resin.

The specimen was chosen for exhibition in the new Wonder Bays in the Hintze Hall, opened in 2017. This required another move, and the specimen was stabilised before being dismantled, transported, and reassembled in its new position.

Stabilisation and dismantling

After an initial condition report was completed, the specimen underwent a series of treatments prior to any dismantling. The specimen had accumulated a thick layer of particulate contaminants, and was cleaned with soft goat hair brushes and low-pressure vacuum before condition assessments and photography could be carried out. Further cleaning was executed using cosmetic sponge (Figure 1) and lint-free tissue dampened with Industrial Methylated Spirit (IMS). Cleaning revealed cracks in the vertebrae, ribs, and leg elements caused by lateral movement and fluctuating relative humidity. Two large diagonal cracks followed the presumed path of the armature that had been inserted into the pelvis, causing potential separation of the upper section, which was

held up by the armature, and the lower sections, which were now resting on the tops of the femora and had caused compaction. Cracks were also found within the old gap fill that held the foot bones together, and delamination was significant on the ribs and tusks. Areas of structural weakness were stabilised using Butvar® B98 consolidant (5% in ethanol), Butvar® B98 adhesive (20% in ethanol) and Butvar® B98 gap-fill (20% in ethanol mixed with glass microballoons (fumed silica), pre-tinted with earth pigments). As a filling material, Butvar® B98 was found to have a longer working time than Paraloid B72 and microballoon mixtures, and exhibited no problems with bubbles and expansion during curing.

Butvar® B98 is a terpolymer of vinyl butyral, vinyl alcohol, and vinyl acetate monomers. It has been used for many years at the NHM, where strength and stability are required at elevated temperatures, as are often encountered within the galleries. It is also recommended for consolidation of porous fossil material by the American Museum of Natural History (Goldberg and Davidson, 2014). Butvar® B98 is considered reasonably stable (Spirydowicz et al., 2001) and has been found to be reversible with no negative effect on the majority of stable isotopes in bones (France et al., 2015), making it a good choice for scientific specimens. There is, however, some concern about cross-linking over time and a resulting decrease in solubility, meaning it may require stronger solvents to remove (Feller and Curran 1975; Ellis and Heginbotham, 2004). This does not pose a problem with the mastodon, since more polar solvents would not cause damage and, on balance, the issue is of less concern than the risk of physical damage resulting from collapse. Butvar® B98 can also be used as a reversible barrier with irreversible resins (Anderson and Podmaniczky, 1990), so was used on the mastodon as a coating where in-painting with acrylics was necessary for aesthetic reasons.

Figure 2. The leg armature extends into four sections of tree trunk, which are braced with a network of curved metal bands. Image: L.Allington-Jones, © The Natural History Museum.

Figure 1. The vertical line on the pelvis delineates the division between the dusted area (facing left) and the area which has been further cleaned with cosmetic sponge (facing right). The blue whale model keeps a watchful eye in the background. Image: L.Allington-Jones, © The Natural History Museum.

The toes of the mastodon had to be carefully excavated from a cement-like base decoration before the remainder of the plinth was deconstructed. This polymer mix was softened with water to reduce vibrations as dental tools and, at greater distance, a hammer and chisel were used. Beneath the plinth, the support system was exposed as a network of iron bands intertwining four sections of tree trunk, within which the leg supports were embedded (Figure 2). The skull cast had been installed to encase the armature which supports the tusks, so it had to be removed. The two halves of the polyester skull were separated using a rotary tool along the flash line and the plaster of Paris gap-fill around the tusks was carefully chipped away. Once the top of the skull had been removed, the Victorian armature supporting the lower jaw and tusks was revealed (Figure 3). This was labelled and photographed to ensure that it could be replicated during re-installation.

Figure 3. The Victorian armature inside the skull cast, which links the tusks to the torso. Image: L.Allington-Jones, © The Natural History Museum.

Elements which were easy to remove, such as the scapulae, were detached, but each leg and the rib cage would have suffered damage if disarticulated so these were treated as intact units. Wooden frames were constructed to support the torso and each individual leg during transportation between the two galleries (Figure 4). The pelvis was secured with Relic Wrap™ (polytetrafluoroethylene film) and padded ratchet straps to prevent movement of cracks during component release and transportation. The dismantling was carefully planned and helped hugely by the sketches published by Lindsay (1991). Risk assessments were created for the dismantling and removal of elements, taking into consideration the specimens surrounding the mastodon as well as the general public, since the main gallery remained open for the majority of the project. The whale skeleton, suspended directly above the mastodon, caused particular inconvenience because it did not allow for enough clearance for the torso to be hoisted upwards off the legs. Instead, the weight of the torso needed to be suspended in situ using block and tackle attached to the cross beam of the scaffolding whilst the legs were unbolted and canted out from beneath using crate skates.

Figure 4. One of the rear legs, ready for transportation, is cushioned by a Tyvek® pillow filled with Plastazote® off-cuts. Image: L.Allington-Jones, © The Natural History Museum.

The de-installation was nerve-wracking, with the (unfounded) worry that the Victorian armature was under pressure and could spring outwards when the bolts were released. Many spotters were needed when hoisting down the tusks (using a mobile hoist and straps) to ensure that the surrounding specimens were not damaged. In fact, only two issues of concern occurred. The first was that the torso tried to rock backwards when the weight of the tusks was removed. The torso was therefore winched forwards using ratchet straps attached to the scaffolding, to prevent stress on the remaining joints (or even a slow backwards collapse) whilst the legs were removed.

The second was that compression cracks opened up in the femoral heads when the weight of the pelvis was relieved. The move to Hintze Hall itself was achieved using padded pallets and crate skates. It required a wooden platform to be built across the other plinths in the Mammal Hall, plus the removal of one giraffe and three rhinoceroses.

Installation

Due to spatial constraints caused by the new plinth in the Hintze Hall Wonder Bay, the legs were hoisted using a chain pulley system attached to scaffolding (Figure 5). Once the legs were roughly in place, the original metal bands were reattached around the tree trunk sections and then the torso was lowered on top using chain pulleys. Bespoke metal spacers were manufactured and fitted to the joint between the pelvis and femora to prevent further compression damage. The two halves of the skull were joined using Milliput® (2-part epoxy putty) over twists of acid-free tissue (Figure 6), with a barrier of acid-free tissue surrounding the tusk sockets. Putty was chosen in preference to polyester resin and fibreglass patches due to health and safety considerations. The putty was over-painted with acrylic paints.

Conclusion

Several lessons were learnt from, or exemplified by, this project. Apart from being unsightly, and increasing the risk of pest infestations, fire, and chemical reactions, particulate contaminants can hide deterioration and structural problems in display specimens like the mastodon. Conservation plans must be flexible, and treatments must evolve during a project to accommodate issues revealed by cleaning that may not have been apparent in initial assessments. The project also shows the value of old records, and the need to investigate the history of a specimen. Risk assessments proved invaluable for creating a holistic perspective and promoting consideration of the surrounding environment.

The mastodon now stands suitably framed by the terracotta archway, in the newly refurbished Hintze Hall, where it will hopefully stay for many decades to come (Figure 7).

Figure 5. At this stage the rear legs have been hoisted into position, but the wrapped pelvis is yet to be lowered down to meet them. Image: L.Allington-Jones, © The Natural History Museum.

Figure 6. The unpainted putty which secures the two halves of the skull cast can be seen here as an orange band. Image: L.Allington-Jones, © The Natural History Museum.

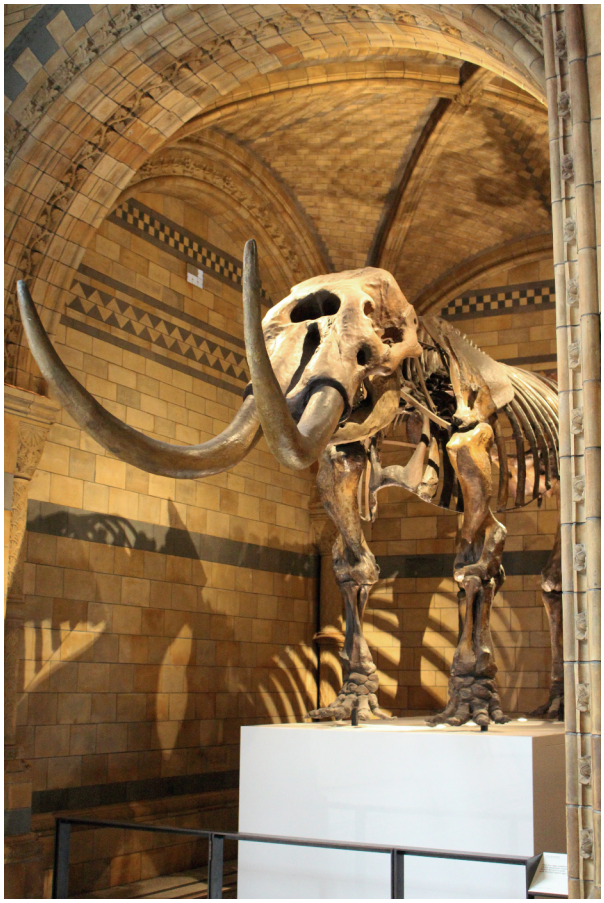

Figure 7. The Mastodon installed in Wonder Bay 1. Image: L.Allington-Jones, © The Natural History Museum.

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A whale skeleton is moved

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Abstract

The largest specimen in the collection of the Museu de Ciències Naturals de Barcelona (MCNB), the skeleton of a Fin Whale *Balaenoptera physalus* (MZB 83-3084), was suspended as a mounted exhibit from the ceiling of the Museum's temporary exhibition hall from 1986 onwards. However, in 2009 the MCNB was modernised and enlarged with the addition of a new building, which involved the moving of the skeleton from where it presided over the staircase of the main hall of the public entrance to the new building to be mounted as if in the act of diving. The 100-year-old bones of its skeleton were dismantled, all bones conserved, moved in mounted sections to the new building, and rehung there from the ceiling. The whole project took two years to complete and culminated in the final challenge of suspending the skeleton in its new position. In the end, the complexity of the task was far greater than we first imagined due to an unforeseen incident during the dismantling process, the great quantity of dirt and fat on the bones, and the delicate work required to position the fragile skeleton above the staircase. In order to ensure that the skeleton was safely mounted and posed no danger to visitors, numerous specialists had to be employed on the project. Greater coordination then expected was required during the work and many working days were long and highly intense. The fruitful teamwork that characterised the whole project was the key to ensuring that this much-beloved specimen continues to be displayed for visitors to enjoy.

Keywords: Fin whale, mounted skeleton, conservation treatments, transport, new location, structure

The whale skeleton in the collection of Museu de Ciències Naturals de Barcelona

Museu de Ciències Naturals de Barcelona (MCNB) possesses a mounted skeleton of an adult Fin Whale *Balaenoptera physalus* Linnaeus, 1758 (MZB 83-3084) that beached at Cap Ras (Llançà, Girona) in June 1862. The skeleton was purchased by the Rector of the University of Barcelona; its bones were prepared in the sea and then transported to Barcelona, probably by boat. The skeleton was mounted and displayed in the main hall of the University of Barcelona until its museum closed in 1917. The MCNB Board decided to acquire part of the University's collection. A carpenter dismantled the whale skeleton and transported it to the Martorell Museum, where it was remounted on a large platform supported by iron columns. Due to a lack of space, in 1923 the zoological collection of the Martorell Museum was transferred to the nearby building of the Castell dels Tres Dragons. The Museum's archives record that the skeleton was installed on the first floor of this museum in 1925. In 1947, the whale was moved onto the ground floor using a system of pulleys to lower the heaviest parts of the skeleton. In 1986, the Museum began renovation of its ground floor, and henceforth the

skeleton was suspended from the ceiling. The team that carried out the reforms was led by the architect Cristian Cirici (Studio PER, Arquitectes. Pep Bonet and Cristian Cirici). From 1986 onwards, the ground floor of the Castell dels Tres Dragons was used for temporary exhibitions, presided over by the whale skeleton, and is to this day still known as the Sala de la Balena (the Hall of the Whale) (Figure 1).

The modernisation of the MCNB and its new building

In 2009, the MCNB set in motion a project aimed at modernising and enlarging the space devoted to exhibitions and other activities. The new building, designed by Herzog & de Meuron and constructed in 2004, is an original, blue-coloured triangular building, known as the Forum Building. The project to adapt this new space for use as a museum was carried out by the same architects. It was decided that the whale skeleton would be suspended above the stairs of the main entrance in a natural, eye-catching position. Herzog & de Meuron accepted the challenge of designing a new position and shape for the skeleton. Its installation in the new building was complex; it first had to be taken down from the ceiling of the Castell dels Tres Dragons, and then removed to be examined and restored, as it was not possible to work in the new building. When work on the skeleton was complete, it was returned to the Castell, ready to be moved to its new emplacement. Mounted sections of the skeleton were transported to the Forum Building and, finally, remounted over the stairs in the main entrance hall. Many different experts from a great variety of disciplines were needed to perform all the various phases of the operation.

Before being taken down, the skeleton and the structure that had supported it since 1986 were closely examined and documented. Graphic documents with drawings and photographs of the whale suspended from the ceiling were taken (Pérez et al., 2011) and incorporated into a highly valuable document describing the history of this specimen in the Museum's collection. This study revealed that the skeleton had accumulated a large amount of dirt and foreign bodies over the years, probably dating from its original emplacement, which had led to severe degradation and damage to the bones.

Figure 1. Mounted skeleton at Castell dels Tres Dragons (Barcelona) in 1986–2010. Image: © MCNB / Jordi Vidal.

Dismantling

The skeleton took a week to be dismantled, in June 2010. Scaffolding was erected, and a system of pulleys was used to take down each bone. Firstly, the joints were dismantled one-by-one, labelled and prepared for transport. On the day the cranium was to be taken down, after dismantling the hemimandibles, the support of the chondrocranium became unstable and this section of the skull broke at its most fragile point where the nasal bones and the maxilla and premaxilla bones join. The resulting collapse caused these bones to break and the condrocranium to splinter into a number of fragments (Figure 2).

Figure 2. Fragments of the maxilla and premaxilla. Image: © MCNB.

When the skeleton was completely dismantled, a fresh examination of the bones, especially of the cranium, revealed that the skeleton had in fact been painted. Also, old fractures in the cranium and a loss of bone matter were detected, and it was found that, during previous mountings, many perforations had been made in the bones of the skeleton. The accident was probably the result of a series of circumstances including the position of the cranium in its original emplacement, just a few centimetres below the ceiling, which made it impossible to observe exactly where the bones had previously been broken. In the Museum archive there was no record of any previous conservation work or treatment, or any details of previous installations. The accident caused us to reassess the objectives of the project. First of all, we discussed whether or not it was still feasible to suspend the skeleton as planned. Other proposals included suspending it in another site and the replacing of the original cranium with a replica. However, we eventually decided to continue with the original project, a decision that greatly affected how the subsequent phases of the project were carried out, given that we were aware that the difficulty and risks involved had increased significantly. When taking decisions, it was essential to ensure that the skeleton would not put visitors at risk and that the skeleton itself would be maintained intact. We employed two companies with specific expertise to take charge of the suspension of the whale from the ceiling, and all the parties involved had to dedicate more human resources to the project than initially planned.

Conservation

All the bones belonging to the skeleton were transported to the laboratory of the Catalan Institute of Palaeontology Miquel Crusafont (ICP) on the campus of the Autonomous University of Barcelona (UAB), around 20 km from the city of Barcelona. The members of this institute's conservation team had previous experience of working with the skeletons of large mammals in the MCNB collection. A platform was purpose-built to support the weight of the skull, and all the bones were labelled. We found that all the iron pieces from the previous mountings had rusted (screws, internal and external supports, and wire braces) and that pieces of wood had been used to plug holes. Pieces of old putty dating from previous restoration work were also found. Almost all of this material was removed by hand. The remains of cartilage, above all on the scapulae, were also extracted manually. Before beginning, different types of cleaning treatments were tested, and results showed that the best option was washing in warm pressurized water with a 1% neutral soap solution, followed by brushing by hand (Figure 3). The removal of the external layers of dirt, and then the paint and fat, were carried out successively without allowing the skeleton to dry in between treatments. The specimen was dried at the end of the process, in the shade in the open air and then under temperature-controlled conditions indoors. All superficial grime was removed with pressurised warm water, while the paint was removed using warm water, 1% neutral soap, water pistols and brushes. Under the paint, a thick black layer was found (Figure 4), which was removed by

washing in warm water and 1% neutral soap, and using water pistols and brushes. However, the most difficult part of the restoration was the removal of the thick layers of fat, which had not been detected by the pre-restoration examination. The initial aim was to remove the fat using a sparingly applied acetone solution. In the end, a different type of treatment involving more staff had to be employed. Each bone was bathed in a 0.5% sodium hydroxide solution, with 1% neutral soap and tensoactive Teepol G (20% sodium sulphate 20%, and 25% linear alkylbenzene sulphonate acid) to eliminate the surface tension and enhance the degreasing of the inside of the bones. This alkaline solution had a pH value of 10 and helped provoke the exudation and dissolution of the lipids in the bones. Each bone was left for 3–4 days in the solution, up to three times if necessary, and five times in the case of the cranium (Figure 5). Once this process was finalized, the effects of the solution were neutralized by bathing bones in water for as many days as they had been subjected to the degreasing treatment. In the end, a pH value of 7 was reached. To avoid the spread of moulds, a Timol 0.5% solution in water was used. After all these treatments were completed, the bones were bathed in water with 15% diluted 96% alcohol. Rust stains were eliminated using 5% oxalic acid in water applied with paper tissue, and neutralized subsequently with water and tissues until a neutral pH was reached. Previously, tests with hydrogen peroxide and acetic acid were performed.

Bones were dried in specially prepared, dry, well-ventilated spaces with no direct sunlight. All bones were consolidated with vinyl resin (Mowilith-60) diluted in 5% acetone and 10% alcohol. In the end, despite the complexity of treating so many bones with such high fat content, and the sheer weight of the cranium and mandibles, the results were highly satisfactory. The conservation work was performed by seven specialists over a period of five months, under the direct supervision of the Museum staff. A full report including copious graphical material was drawn up of the whole process. Subsequently, an article has been published in a journal devoted to conservation tasks in which the different phases are explained in detail (Val et al., 2012).

Once all the bones had been cleansed, were fat-free and strengthened, the tasks of reconstructing the broken bones and putting the finishing touches to the conservation work began. Small fragments and cracks were joined using the two components of a powerful epoxy resin, ADEKIT A135. In some cases, ARALDIT 2020 was injected. The internal anchorage of the large bone fragments was performed using stainless-steel rods penetrating 8–10 cm into the bones, and ADEKIT A100 epoxy resin injected into the points of incision of these rods. Bone mass lost due to breakages and previous restoration work was replaced by an epoxy putty (NURAL 35-Pattex). The finish to the repair work was toned down so that it would be immediately recognisable. The broken part of the cranium that was restored was given a finish with a more neutral tone than the original colour, using acrylic paint on the consolidated part of the bone mass. Once the conservation tasks were over, the bones were transported back to the Castell dels Tres Dragons by the company Art% S.L, where a space was set aside for the remounting of the skeleton (Figure 6).

Figure 3. Cleaning tests with pressurized water designed to remove the black dirt under the paint. Image: © MCNB / ICP.

Figure 4. Black dirt underneath layers of paint on the skull. Image: © MCNB / ICP.

Figure 5. Elimination of the fat at the beginning of the first washing of a number of vertebrae. Image: © MCNB / ICP.

Figure 6. After conservation, the skull was transported in a custom-made box. Image: © MCNB.

Figure 7. All conserved bones were studied and labelled before being fitted together. Image: © MCNB.

Installation

The Museum sought other experienced companies to install the skeleton. There were no precedents for the installation of a skeleton of this size above the stairs of a museum entrance hall, and this part of the project was by far the most complex. In the end, the Museum opted for a multi-disciplinary team consisting of Museum staff and experts from external companies, in which all parties provided expertise in their own fields. Finally, the companies Gabinete de Estudios Ambientales (GEA) and Canarias Conservación, specialists in the assembly of skeletons, and with experience in installing whale skeletons, were chosen for the project. The companies Grop S.L. and Art% S.L., both specialists in setting up exhibitions and transporting works of art, and with long experience in working with delicate and fragile loads, were also chosen. The architects from Herzog & de Meuron, in conjunction with the structural architect Nacho Costales (Bomaimsa), designed the project and supervised the hanging of the skeleton from the ceiling above the stairs.

A team of six workers from GEA/Canarias Conservación worked in May–July 2011 on the remounting of the skeleton. First, all the bones were arranged in order in the main hall, and each was subject to detailed scrutiny (Figure 7). All the bones were studied, documented (orifices, losses, deformations, restorations, etc.) and then photographed. Next, they were weighed on a digital scale or, as in the case of the largest bones, with a digital dynamometer using a block and tackle suspended from the ceiling. Finally, all bones were measured; the results were published by Carrillo et al. (2014). The size and weight of each bone provided valuable information for manufacturing the structures that would sustain the weight and volume of the complete skeleton.

The skull

The skull was not fully mounted at the ICP, since its final appearance would depend on the nature of the structure to be used to suspend it from the ceiling. GEA used stainless steel to join the maxilla and premaxilla to the nasal and frontal bones. The fractured parts of the skull – in particular, the vomer – were reinforced with epoxy resin and glass-fibre fabric, applied over the consolidated bones. A stainless-steel rod was used to join the hyoid apparatus to the cartilage. High-density polyurethane foam was used to reconstruct the jugal bones and the left-hand ascendant maxilla process. The structures

joining the skull and the jaws were made from stainless steel so that the mounting can be taken down if need be (Figure 8). In collaboration with the architects, an independent external structure for the skull was designed and built to withstand the weight of this part of the skeleton when hanging from the ceiling, and to absorb the tension in the cables supporting the specimen from the ceiling. This structure was made of stainless steel and possesses a number of rings for anchoring the cables used to suspend the skeleton. Detailed information and images can be found in Costales (2016). A temporary wheeled platform was also built, on which the skull and jaws were placed for transport to the new museum.

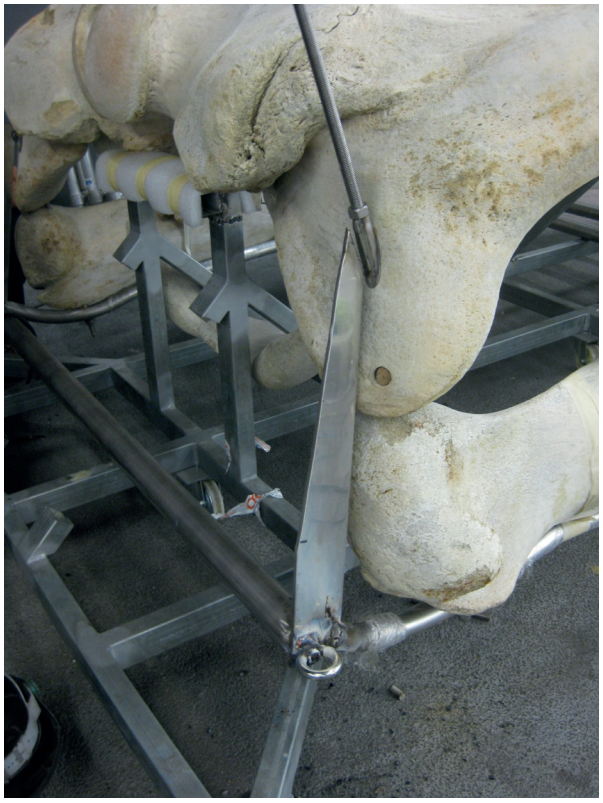

Figure 8. Joining of the cranium and mandibles with stainless-steel material. Image: © GEA.

The spinal column

The spine was split up into four sections, each with a maximum length of 4 metres, a size determined by the maximum transportable length and, above all, by the capacity of the elevator in the new building. For each of the four parts of the spine, a wheeled platform was manufactured. Holes were drilled in the central parts of all vertebrae except the atlas, with either a 47-mm- or 16-mm-diameter hole in the case of the final six caudal vertebrae. The extracted bone segments are preserved in the Museum's collection. Then, a steel tube – 44-mm wide with 2.7-mm-thick walls – was passed through all the vertebrae of the spine (Costales, 2016). A total of 50 polyurethane intervertebral discs were manufactured and placed, with protection from neutral material, between the vertebrae. This type of material is mouldable. To prevent the vertebrae rotating and to ensure that the project was reversible, the vertebrae were soldered to a tube using two stainless-steel plates (40 x 3 mm and 10-mm long) (Figure 9). Two perforations in the plates were made for two stainless-steel screws (60 x 40 mm). All the vertebrae were threaded onto the stainless-steel tube except for the final six caudal vertebrae, which were placed on a threaded rod. The anchorages for the cables suspending the spine from the ceiling of the new building were installed as follows: 10 specially made pieces were placed in the posterior part of cervical 1, in thoracic vertebrae 8 and 12, in lumbar vertebrae 5, 7 and 13, and in caudal vertebrae 3, 5, 10 and 14. Each anchorage consisted of three 16-mm threaded sections of rod, two placed in the upper part, one in the lower part, joined to the tube via a perforation and soldered together. Finally, the corresponding haemal arches were attached. The stainless-steel tube supporting the spinal column is arched to give the skeleton a more natural swimming/diving position. Four groups of cables support the steel tube to prevent any buckling (Costales, 2016).

Figure 9. Plates in the vertebrae designed to prevent movement. Image: © GEA.

The thorax

The ribs were attached to the transverse processes of the vertebrae using hooks in the bone – one at the head of each rib and the other at the far end of the process of each vertebra – that were joined by nuts, washers and security bolts. The thoracic cage has a number of built-in reinforcements: a stainless-steel plate linking the rear part of the first pair of ribs, and

four steel tubes reinforcing the inside of the thorax, which guarantee that the inclination of the thoracic cage – once suspended – would not damage the steel plates.

Pectoral region

When the skeleton was dismantled, a number of fin bones fins were found to have been replaced at an unknown date by pieces of wood. Substitutes for these missing bones – replicas of the corresponding bones on the opposite fin – were made: 32 phalanges and the radial carpal bone of the left fin were manufactured from polyurethane reinforced with Eporai 450 resin. The two fins were installed with all their bones or their substitutes in the appropriate positions and attached using stainless-steel rods with screw threads, washers and bolts. The two fins were transported separately. To attach the scapulae to the thoracic cage, three holes had to be drilled in the scapulae and in the ribs. The mounting of all the bones is described in the final report prepared by GEA, illustrated with a full range of photographs depicting the details of all the materials used in each part of the skeleton.

During the mounting of the different parts of the skeleton, the design of the structure needed to support the weight of the skeleton in suspension was decided upon. The challenge was taken up by Herzog & de Meuron, the architects who had designed the Forum Building. In the end, a joint proposal for the structure was made by the specialists of all the participating companies.

Transport to the new building

Four wheeled platforms were built with nylon bearings and lifting platforms to support the mounted and immobilized skeleton. These platforms were manufactured out of tubular stainless-steel sections (like the support structures) with ISO metric 12 screw threads and fastenings. The actual transport was carried out using rigid trucks equipped with lifting platforms and isothermal chambers to guarantee the temperature and humidity conditions (T 20ºC, H.R. 50–55%) established by the Museum. The company in charge of the transport decided not to wrap up the largest and most fragile bones to allow visual checks to be made of the sections of the spinal column and skull parts.

Suspension from the ceiling

The company Art% S.L took charge of the installation of the skeleton above the stairs. Aluminium scaffolding was erected with different modules to allow for two work levels in the area between the top of the stairs and the ground level, where the entrance door from the street is located. Before installing the skeleton (but with the scaffolding already in place), vertical and horizontal movements were tested using an object with a similar volume to the whale's thoracic cage (the largest part of the skeleton) to establish the best position for the spider crane (model URW-376). Once the precise movements required had been defined, and taking into account that there would also be a highly complex system of cables, the crane was placed on a raised part of the first floor, to the left of the stairs, almost vertically in line with the final position of the skull.

The main factors that determined how the installation was carried out were the aesthetic effect required for the skeleton and the many cables it hung from, and the extreme fragility of the conservation work carried out on the skull, which was treated like any other highly delicate specimen. Of the two, the first of these factors was the most difficult to resolve. The fact that there were no completely vertical cables to take the strain of the skeleton obliged the respective companies to carry out a series of tests and trials to gauge the initial position of the thoracic cage, the part of the skeleton that was judged to be the most appropriate starting point for the whole composition. In the end, the thoracic cage moved 25 cm from its theoretical position once suspended, a displacement that was corrected so that it would hang in exactly the desired position. There was no need to alter the position of the skull once it was hung, due to the number of cables used and their more vertical positions (albeit never in fact completely vertical) compared to the cabling used for the thoracic cage (Figure 10).

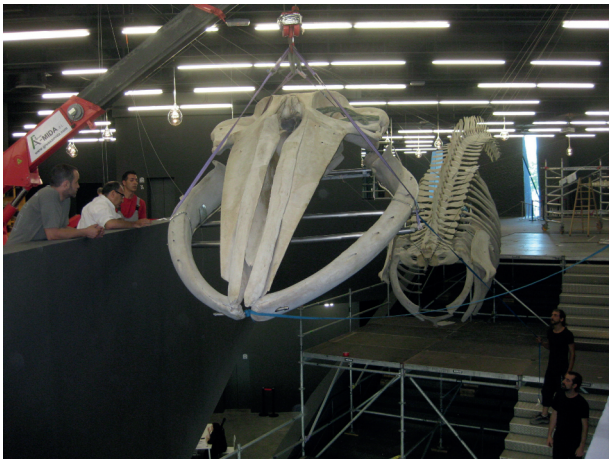

Figure 10. Skull suspended by a crane before being attached to the rest of the skeleton. Image: © MCNB.

Once the reaction of the cables to the suspension of the parts of the skeleton was understood, the remaining parts of the specimen were installed much more easily and with fewer difficulties than expected.

One of the issues that most complicated the hanging was the natural position given to the skeleton. During the pre-mounting phase, the specialists and architects had decided on a position for the skeleton that took into account the dimensions of the stairs and the final position of the whale. Any change in the initial position and inclination of the thoracic cage (the first section of the skeleton to be hung) would provoke changes in the positioning of the tail parts. Although the planned measurements were followed to the final millimetre, the flexibility of the cables (over 10-metres long in many cases) generated a problem that became noticeable as the work progressed: the natural curve of the tail meant that the skeleton almost touched the ground of the first floor; thus, the slant of the thoracic cage had to be modified. As a result, other smaller rectifications and changes in tensions to take advantage of the strength of the most vertical cables had to be implemented. Throughout the work, A4 steel was used in all the elements in the composition of the skeleton, both in the parts that joined the different sections of the skeleton and in the smaller pieces that were used elsewhere in the mounting. A Genie work platform was used to correct the attachment and position of one of the fins, due to the small change in the overall position of the skeleton. Once all these modifications were completed, a full review was carried out by the architects to check whether or not the skeleton was stable; to date, no movement has been detected. Finally, once the project had been concluded successfully (Figure 11), the new installation of the skeleton was opened to the public.

Evaluation

Some of the many reasons why a museum chooses to move a large skeleton include the opening of an exhibition, the need to study or conserve the specimen in question, or a desire to change its position (Larkin, 2016). In our case, the motive was the opening of a new MCNB building for exhibitions. The project started with the gathering of as much documentation as possible about the specimen and about similar projects. We visited the Toulouse Natural History Museum (France) on a number of occasions to gather information, and a few weeks

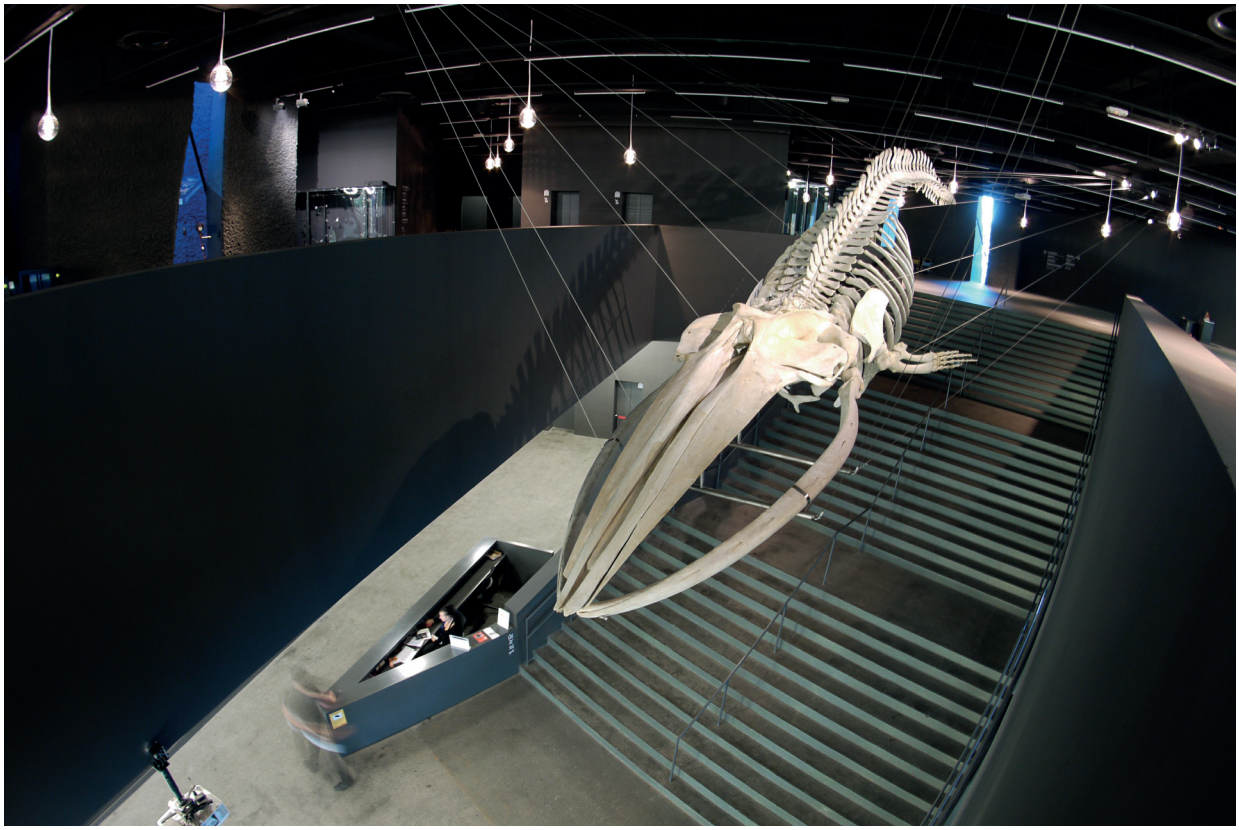

Figure 11. Skeleton exhibited from July 2011 in the Forum building. Image: © MCNB / DISE-Vicente Zambrano.

before ending work in Barcelona, museum staff were present at the mounting of a large skeleton in the Museo Nacional de Ciencias Naturales, Madrid (Spain). As well, meetings were held with the companies involved before work got underway. The fragility and the difficulty in manipulating the skeleton was evident from the very first days of the project, above all after the breakage. Thus, during the rest of the project the main goal was to avoid at all costs any further incidents, above all to the previously damaged part of the skull. The skull is undoubtedly the most fragile part of the skeleton; its large, heavy bones readily become unstable, as the centre of gravity of the whole skeleton is further forward than its geometrical centre (Costales, 2016). On occasions, the idea of abandoning the suspension of the skeleton over the stairs was mooted; nevertheless, our fears and doubts were transformed into a large dose of collective awareness of the problems, which in the end was one of the keys to its success.

The conservation-restoration team's previous experience and their enormous effort ensured the success of the work undertaken. The cleaning and degreasing techniques used were similar to those employed on other marine mammals, as described by Larkin et al. (2015). Nevertheless, although the sheer size and weight of certain bones of an adult Fin Whale pose additional difficulties, evidence of the success of the operation is perfectly visible in a visit to the Museum to view the skeleton.

The mounting of the skeleton parts and its transport to the new building were carried out without further incident. The design of the structure supporting the skeleton and the way in which it is anchored to the ceiling are novel and somewhat risky undertakings –– even so, for the architects involved, the whale skeleton is in fact a relatively light structure! The most worrisome factors that had to be taken into account were the need to ensure that the skeleton was not damaged in any other way, that all the bones were well preserved in the long term, and, above all, that visitors to the new public spaces in the Museum would not be put at risk. Thus, in the final design the cranium is supported by a metal structure that is suspended from the ceiling by steel cables. None of the individual bones are subjected to any pressure or tension from the ceiling since the whole skeleton is traversed by a tube supported by the cables welded to the ceiling. The expertise of the company – well-versed in working with highly valuable, often very fragile and voluminous works of art – that undertook the delicate task of suspending the skeleton from the ceiling was a guarantee that the most complex part of the whole operation and the handling of the skeleton would be performed correctly.

The skeleton of this Fin Whale, measuring 18.30 m in length and weighting 1,162 kg, has been on display in the MCNB since July 2011. The inauguration of the whale in its new site was marked by a press conference and the event was highlighted in many news broadcasts. The whale was a beloved feature of the previous museum and continues to be a key element in the new exhibition. The display of such an impressive and iconic specimen captures the attention immediately of visitors and is a superb way of describing its history as a museum specimen and of offering clues as to the biology of the species (Hawkins, 2006). The whole project was filmed and the museum display on the specimen includes a film-loop of the process (https://vimeo.com/55256040), which gives a good idea of the work involved and helps people appreciate more fully the work that the Museum undertakes.

Since the installation was finished, six years ago, the state of conservation of the bones and the general structure has been closely monitored. The substitution of the old metallic parts with new ones that respect the bone structures, together with the removal of the accumulated fat and rust that had never previously been carried out in this specimen (Pérez, et al., 2011), ensures that the bones are today much better conserved than ever before. The possible appearance of more fats could alter and age the materials used to adhere and conserve the bones, and render them fragile and ineffective (Val et al., 2012). Detailed monitoring will guarantee that lipids can be eliminated whenever and wherever necessary.

As a chordate curator, I was put in charge of the complex tasks of moving the largest specimen in our collection – at that time suspended from the Museum ceiling – from one position to another. Obviously, my training as a biologist was not suitable for designing such a project and putting it into practice. In the Museum we had some experience of restoring large skeletons and of mounting small skeletons, and had also set up a preventative conservation laboratory a few years previously. The project began with a team of experts in various fields but this changed overnight after the breaking of part of the cranium. Henceforth, we had to focus on finalizing the project and avoiding any further damage to the skeleton. All the care and common sense that I used from the beginning was not enough to prevent the breakage. If I ever have to undertake a similar project, I would lengthen the preparatory phase, keep an even closer watch over

the whole project, and work with experts right from the start of the project. Many lessons were learnt during the project, which all involved recall as a period of great intensity interspersed with numerous unforgettable moments. The installation of the skeleton in its new home was a positive experience for many people and the proof of its success, the result of the keen eyes of architects, restorers and biologists, is there for all to see.

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A moving experience: The redevelopment of the University Museum of Zoology, Cambridge

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Abstract

A plan to redevelop the University Museum of Zoology, Cambridge (UMZC) and the David Attenborough Building in which it is housed began to take shape in 2010. Beginning in June 2013, three million specimens housed in five storerooms and a gallery had to be safely moved to newly-designed stores with limited time, money, and staffing levels. Advocacy amongst key partners played a crucial role in maximising resources, and an ambitious plan to recruit collection volunteers was developed. Teaching and researcher access had to be maintained throughout the redevelopment.

This paper serves as an introduction to the first half of the project, from 2010 up until early 2015, which covers collections-related aspects of the planning, initial packing and moving phase. Larkin (2016a,b) discusses methods used to pack and move the largest gallery specimens.

Keywords: Natural History, Collections, Advocacy, Volunteers, Packing, Conservation, David Attenborough Building

Introduction

The University Museum of Zoology, Cambridge (UMZC) was founded in 1865 (Willis and Clark, 1886) and can trace its origins to the Harwood Collection of Comparative Anatomy (1814) and the Cambridge Philosophical Society collections (1819). Built on the former site of the University Botanic Gardens (Parker, 2006), the collections were housed in an overcrowded Victorian gallery (Figure 1) until a major redevelopment of the site in the late 1960s (Calder, 2008), reopening in 1971 in the Arup tower (now renamed The David Attenborough Building).

With over three million zoological specimens housed in five storerooms and a public gallery, the collections are accessible for undergraduate teaching, research, and public engagement. Over 100 researchers from around the world use the collections every year for research across the disciplines.

In 2010, the Museum was presented with an ambitious vision to redevelop the Arup Building to take advantage of the departure of the adjacent Material Sciences Department, bringing together university academics and a consortium of biodiversity conservation organisations and practitioners housed in the Cambridge Conservation Initiative (CCI).

The project planners initially considered a six-month period to pack and relocate the collections with

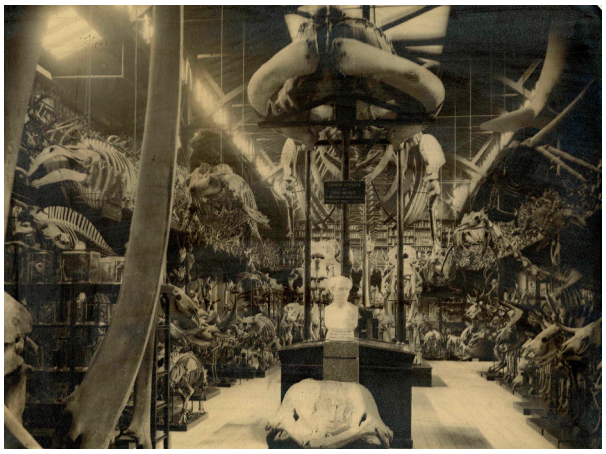

Figure 1. The museum gallery, circa 1896, showing the need for increased storage capacity. Image: UMZC.

existing staff levels but by early 2013, just months before the Museum was due to close, had reassessed the situation after both external and internal consultation. The building design itself, as discussed in the Methods section, changed to reflect the results of this consultation. The Museum closed in June 2013 with the aim to pack the collections within 14 months. An added - but much welcome - complication that altered plans was the awarding of a Heritage Lottery Fund (HLF) grant in early 2014, by which time much of the initial planning and packing phase had already occurred.

The requirement to continue teaching during the collections move was a particular challenge, as we simply could not run a reduced service. Specimens required for teaching were isolated at the very start of the move, and for four years teaching itself was relocated to the nearby Austin Building. Practical sessions had to be set up by the collections staff as normal, and specimens tracked for subsequent sessions.

Similarly, research access had to be maintained. Researchers were encouraged to use nearby collections if the nature of their enquiry did not require a unique UMZC specimen, but not refused access. Collections access was only temporarily denied in the weeks before and during the physical move itself. However, word of the Museum redevelopment appears to have temporarily depressed researcher access requests.

Finally, but not discussed in this paper, hanging outside the Museum's entrance was a 21-metre fin whale (*Balaenoptera physalus* (Linnaeus, 1758)) which, in order to provide café space, had to be dismantled from its external podium and relocated to a new purpose-built entrance foyer.

Methods

Advocacy and external consultation

The tentative six-month estimate to pack and relocate the collection made by the project planners (including external contractors and University of Cambridge employees) was a first attempt to gauge the scale of the problem. When decision-makers are not fully informed as to the challenging nature of such collections, advocacy is crucial (Viscardi, 2013). Although not natural historians themselves, many of the architects, builders, and project planners were enthralled by the collections and, through a programme of tours, greater understanding was gained. Once introduced to iconic specimens such as the dodo (*Raphus cucullatus* (Linnaeus, 1758); UMZC. 415.K) and our fin whale (UMZC.C.13), the delicate nature of the collections and the importance of their care were made clear. Above all, the unique problems associated with moving a museum collection and the timescales required were repeatedly emphasised.

The University had already contacted a freelance conservator, Nigel Larkin, to report on the feasibility of moving the fin whale skeleton. Based on this, and

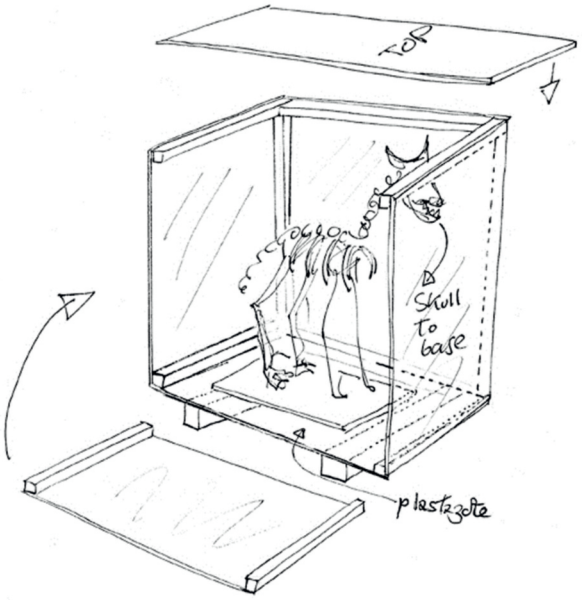

Figure 2. Sketches with the Packing and Moving Report, even if they were not eventually used, provided a useful guide for planning. Image: N. Larkin.

wishing for an independent opinion, Mr. Larkin was further commissioned to produce a detailed time and motion study coupled with an estimate of material usage and associated cost.

The resulting Packing and Moving Report laid out clear person/hour timescales that all parties understood. Packing techniques were suggested with materials fully costed and summarised (Figures 2 and 3). Through this, both the Museum and project planners more thoroughly understood the challenges faced, and a more realistic timescale of 14 months and an adequate budget for materials and staffing was provided.

Additionally, the report altered the very design of the building and the approach to packing and moving the collections. The original plan to move the collections offsite proved more costly than altering the building and project schedule. Thus, it was decided to divide the Arup Building redevelopment into two phases by first creating new stores in parts of the building unoccupied by the Museum, whilst the collections were packed in the old stores and gallery (Phase One). After completion of Phase One, which was to take 14-months, there was to be a 14-week period to move the collections from the old to the new stores. With the collections safely moved, the Museum gallery and old stores would be handed over to the building contractors for Phase Two and completion.

The report provided a framework (although as the dynamics of the project changed, it was altered) that allowed a project Gantt chart to be created and implemented by the Project and Collections Managers, giving the collections team and volunteers clear aims and objectives.

Bulk purchasing

An additional benefit of the Packing and Moving Report was increased confidence in the estimated volume of materials required. Discussions with conservation equipment suppliers were made from a position of strength when negotiating bulk discounts.

Section/specimens		Internal depth cm	Time to pack (hrs)
Man's ancestry			
primate skulls and mandibles	1 x Euro small 1 x Euro small Tissue & plastazote	22 13.9	1
Rodents			
Townsend's ground squirrel, northern palm squirrel, least chipmunk, Californian ground squirrel, grey squirrel, harvest mouse with upright straw. Greater Egyptian gerboa, hazel dormouse, Mongolian 5-toed gerboa, Ord's kangaroo rat, meadow jumping mouse, field vole, European water vole, Norway lemming, wood rat, striped hamster, pygmy gerbil, wood mouse or long tailed field mouse, brown common or Norway rat, black house or ship rat, grey hamster, short tailed pouched rat, lead pipe, Mongolian Tsaganomys sp and gnawed wood.	2 x Euro small Tissue & plastazote dividers etc	22	1.5
Red giant flying squirrel, red squirrel on branch, crested rat on branch, scaly-tailed flying squirrel	Euro large1 Tissue & Plastazote dividers etc	30	1
Primates			
Potto, Aye aye on branch, Spot-nosed guenon, Slender Loris, Black-eared marmoset	1 x Large euro	20	1.5
Diana Monkey, Humboldts woolly monkey, Martins Guenon, Bushbaby	Wooden crate 75x 50 x 55		3
Ruffed lemur, ring tailed lemur, Chimpanzee, Spectral tarsier	1 x Large euro	40	1
Abyssinian colobus x 2, Proboscis monkey	Wooden crate 120 x 90 x 55		5
Giant lemur skull: Lay down in a crate with its plinth	1 x small euro	22	.5

Figure 3. A snapshot of one of many tables from the Packing and Moving Report, detailing the number and dimensions of crates required and the estimated time taken to pack. Image: N. Larkin.

For example, the cost of acid-free paper sheets was reduced from £24 per 500 sheet pack to £16 per pack, providing 100 packs were ordered at a time. Similar discount rates were agreed for Tyvek and acid-free paper rolls.

The biggest cost saving involved 1500 Eurocrates, detailed in Mr. Larkin's report and ordered together (but delivered in batches). In contrast, had small batches (50 – 100 units) been ordered at a time, the cost would have been £10,000 higher.

Bulk ordering also resulted in additional savings in terms of staff time spent processing orders. Large bulk orders took less processing time than multiple small orders and supplies were not lacking when needed, resulting in less interruption when packing specimens.

Volunteer training

The University Museum of Zoology did not have a substantial record of volunteering before the redevelopment began, with most volunteers being University students or people otherwise affiliated with the Department of Zoology. An ambitious plan was put in place in the spring of 2013, with the help of University of Cambridge Museums Conservators and Volunteer Coordinators, to recruit over 30 volunteers in three batches and train them in 2-4-day packing sessions. Targets for the number of volunteer hours had also been set by HLF.

Once the Museum's general volunteer documentation (Agreements, Induction Forms, and Expression of Interest) was brought up to date, role descriptions were created and advertised in local volunteer forums, Friends groups, and the University website. The training days were advertised in advance and it was made clear that attendance was compulsory. Applications were shortlisted and, with the aim of training 12-15 people in each batch, up to 20 people at a time were invited to the Museum for a taster session.

As soon as the Museum closed in June 2013, the first potential recruits were invited in. Each taster session involved a behind-the-scenes tour of the Museum and an informal presentation as to the nature of the project and the challenges faced. At the end of the session, the applicants were told to reconsider their interest and get in touch if they were still interested in pursuing their application further. This allowed people to retreat honourably if they felt that the project was not as they expected, and also provided Museum staff with the opportunity to meet the applicants without any firm commitments being made.

15 people out of those who reconfirmed after the first taster session were selected to attend two two-day training sessions, held a week apart. The potential volunteers were briefly trained in basic handling skills, pest identification, conservation materials, and the risks associated with zoological collections. Manual handling training was provided by the University's training office.

Perhaps the most important skill gained involved packing techniques and box-making. Second-hand shop crockery was presented to the trainees with the instructions to build a box and to pack the object with the materials provided (Figure 4). Upon completion, the boxes were dropped (often enthusiastically) down a staircase, after which boxes were exchanged and anonymous group critique of the results was exchanged.

Figure 4. Packing sacrificial crockery on our first volunteer training session. Image: UMZC.

By the end of the first training session, all 15 volunteers were deemed adequately trained and a rota began, which consisted of morning and afternoon sessions on Tuesdays to Thursdays.

Another two rounds of recruitment and training sessions were held and, between June 2013 and December 2014, over 800 hours of volunteer time were given. It is important to note, however, that the volunteers required constant supervision and projects needed to be planned in advance, taking up considerable time for the Conservators and Collection Manager. Such time commitments should be factored into any future packing and moving project plans.

Packing up the gallery

The gallery drawers containing large mammal osteological specimens were considered an entry-level starting point for our new volunteers. Drawers were laid out on large desks within the gallery, alongside benches of clearly labelled packing supplies. Each drawer contained a list of specimens printed from the database, which the volunteers audited before they began packing. Any discrepancies were reported, corrected on the database if appropriate, and signed off. A photograph of the contents prior to packing was included in the finished drawer.

Drawers were lined with either Plastazote or Jiffy foam, and specimens packed within drawers using a combination of acid-free tissue puffs and Plastazote straps pinned together with toothpicks (Figure 5).

One time-saving method we discovered was to ask our departmental receptionist to make tissue puffs during quiet moments. We estimate that, for the packing of the spirit collections alone, our receptionist made somewhere in the region of 25-30,000 puffs. Boxes of acid-free paper and instructions were also made available to the department with requests for help. Pre-made supplies such as these meant less interruption when working on the specimens themselves.

Whilst drawers from the gallery (and eventually stores) were packed by volunteers, the Museum staff focussed on the more complex display specimens. Larger mounted specimens, for example our African elephant (*Loxodonta africana* (Blumenbach, 1797); UMZC. H.4451), giant sloth (*Megatherium americanum* Cuvier, 1796; UMZC.E.261), and giraffe (*Giraffa camelopardalis* (Linnaeus, 1758); UMZC.H.20381) were partially dismantled by Mr. Larkin, who first removed and separately packed the limbs and skulls. The vertebral columns, ribcages, and armatures were wrapped in situ on their plinths and placed in large wheeled crates (Larkin, 2016a). Similar crates were made for our orangutan (*Pongo pygmaeus* (Linnaeus, 1760); UMZC.E.7107.H) (Larkin, 2016b) and large model bird diorama. Being too large to remove from the gallery, these crates were sealed and left in the Museum during the building works (Figure 6).

Similarly, the Museum has five whale skeletons hanging in the gallery (excluding the fin whale) 10 meters above the floor. As discussed in Larkin (2016a),

Figure 5. A before-and-after image of a tapir (Tapirus indicus Desmarest, 1819; UMZC.H.7323) packed by our volunteer team. Image: UMZC.

Figure 6. The Museum upon handover to Phase Two. Note the whales wrapped and hanging from the ceiling and the larger specimens on wheeled, sealed crates. Image: UMZC.

it was considered an unacceptable health and safety risk to totally dismantle and remove these skeletons at such a height, and thus only the skulls and limbs were removed. The skeletons were then wrapped with layers of acid-free paper, bubble-wrap, and Tyvek, and remained hanging in-situ in the gallery during the building works (Figure 6).

The remaining 5,000 display specimens were packed by staff and volunteers upon completion of the drawer packing. Eurocrates and Really Useful Boxes were used for most of the smaller specimens. For specimens being removed that were too large for Eurocrates, bespoke frames made with lengths of 50mm x 50mm planed all round (PAR) wood and a solid wooden base were made easily and quickly in-house. Our volunteers then took the completed frames and cladded them with corrugated plastic (Corex) using screws and washers. The Corex crates were significantly lighter than equivalent solid wooden crates whilst remaining strong enough to protect the specimens (Figure 7).

The mounted bird taxidermy, both in the gallery and bird room, had small magnets fitted to their wooden bases and were packed into Eurocrates with steel sheet inserts, in the same fashion as the Norwich Castle Museum redevelopment (Irwin, 2002). This allowed for the specimens to be moved, even tilted, without falling over or the need to use potentially damaging packing techniques.

Alongside the Spirit Specimen crates (see following section), the contents of all gallery boxes were recorded on an Excel spreadsheet and were barcoded using a Wasp barcode scanner and software. The hand scanner could then be used to search through the

Figure 7. A wooden framed Corex box containing a partially dismantled red kangaroo skeleton (Macropus rufus Desmarest, 1822; UMZC.A12. 21/1), with the tail and skull removed and the main body tied down. Image: UMZC.

substantial Excel spreadsheets generated, allowing for quick auditing in temporary store areas after the collections had been moved. A battery-powered wireless printer also proved invaluable for generating barcodes and labels on the move and within the stores.

Packing the Spirit Store

Whilst the Vertebrate, Bird, Mollusc and Insect Stores were to be moved to their permanent new locations after Phase One, both the Spirit Store and gallery specimens had to be found temporary locations during Phase Two. The gallery specimens were given a temporary home near the new Museum stores in a space not required until project completion. The Spirit Store, due to fire safety, had to be refurbished but remained in the same location. During the refurbishment, however, the spirit specimens themselves had to be temporarily relocated.

With fragile glass jars, hazardous chemicals, and heavy loads, spirit collections have their own particular challenges with regards to transportation (Clark et al., 1994). We had to pack and move 20,000 jars of alcohol and formalin-preserved specimens out of the store, down a flight of stairs (ramps were demolished and lifts were decommissioned during Phase One) and across a building site car park into a purpose-built temporary spirit store located in the nearby Austin Building.

Members of the Collections team placed jars of similar height from each of the 70 bays within the Spirit Store into Plastazote-lined Eurocrates on trolleys. As discussed in Simmons (2014), a spirit collections move is an opportune time to conduct a conservation audit, and specimens assessed as requiring attention were separated to be packed together. Each Eurocrate had a blank label stuck to the side, on which the specimen catalogue numbers were written as the crates were filled. The jars within the crates were wheeled into the Museum gallery, where there was ample space for volunteers to pack them using the pre-made tissue puffs (Figure 8). All staff and volunteers were briefed with risk assessments associated with spirit specimen collections, and appropriate PPE in the form of gloves, lab coats, safety goggles, and masks was provided. Spill kits were made available in case of breakage.

Any lids considered loose, sharp, or in danger of leaking were wrapped with Parafilm, a plastic paraffin film, which acted as a temporary sealant, and the completed crates were stacked and stored in a row. At the end of each day, the Collections Manager photographed the handwritten labels detailing the contents, typed up the data into an Excel spreadsheet, and generated a unique barcode label for each box. This allowed the Museum to quickly audit all 650 crates once placed in the temporary store, and therefore keep track of all 20,000 specimens throughout the redevelopment. This was critical for researcher/student access and for reviewing specimens for potential redisplay.

Figure 8. Packed spirit specimen crates. It took over 650 crates to pack the whole store. Image: UMZC.

The transportation of all the crates, some weighing over 30kg, was hazardous but manageable. The contractors constructed a wooden pulley and ramp system, allowing us to winch each crate individually down the staircase to waiting trolleys with pneumatic tires outside the Museum. Trolleys were then taken across the car park site to the nearby Austin Building for storage. As the temporary storage area had a floor loading limit, each crate was individually weighed, and the weight clearly labelled on the outside of the box. This ensured that we did not exceed the weight limit of the room during storage, and evenly distributed the load.

All 14 tonnes of the spirit collections were therefore moved in late spring/summer of 2014 during good weather conditions, over a four-month period, well before the end of Phase One (Figure 9).

Packing the Mollusc, Vertebrate, Insect, and Bird Rooms

Most taxidermy, mounted skeletons, and other specimens/items not within drawers were packed into Eurocrates or bespoke boxes in the same fashion as the display specimens already described. Mounted taxidermy heads were either relocated to the Austin Building or wrapped in plastic by the volunteers and

Figure 9. Conservator Natalie Jones pushing one of the hundreds of trolley loads of volunteer-packed spirit specimens towards the temporary store. Image: N. Jones

stored alongside the gallery specimens. The remaining specimens were housed in 2,600 drawers, most of which did not need any further packaging, having been adequately packed for many years. The exceptions were highlighted and given further protection by the volunteers.

The Insect Room was unique, in that there was no plan to change the drawers or cabinets (which would have been too time consuming and costly), and in having to move twice. The original Insect Store was on the fourth floor of the Arup Building, and the collection was destined to be rehoused alongside the new stores. However, the old collections space was within the area to be handed over to the contractors at the beginning of Phase One. The insect collection therefore had to be moved early in the project into the gallery, where it remained for some months until the new Insect Room was complete at the end of Phase One.

The move itself

The Museum had its collections packed and ready for moving by the middle of October 2014 and, soon after, a passageway was created from the old Museum Bird Room into the new stores. A 14-week period was scheduled to move the collections, which included the Christmas period.

The staff were split into teams, and each team given a specific store or zone within a store. The volunteering rota was reduced, as there was a risk of having too many teams of people with trolleys blocking up corridors. The new stores were vacuumed, mopped, dusted and dry-cleaned as thoroughly as possible before specimens were transferred.

At the very beginning of the project, it was initially intended that the cabinets from the old stores would be reused in the new stores, along with their old wooden drawers. With HLF funding and the necessity to use the space more efficiently, it was decided that new metal roller-racking with metal drawers should be installed in the new stores. However, to move the collections within the 14-week window, we had to temporarily use the old wooden drawers. These were housed in the new roller racks until after the move, when we had the time to carefully transfer and organise the collections into the metal drawers.

During the stores design phase in January 2014, over 2,600 drawers had their dimensions recorded. Over-packed drawers were noted so that expansion space could be incorporated into the new stores in the required places. With the height requirements of the drawers known, as some teams transferred collections from old to new stores, other teams were in the new stores accurately installing drawer brackets in relevant bays to receive the incoming collections without a delay.

Other methods used to improve efficiency included the modification of a to-be-disposed cabinet in the Mollusc Store, which was strengthened and fitted with wheels. This allowed all 900 drawers in the old Mollusc Store to be moved the 100 metres and transferred to the pre-set brackets safely within three days.

One downside of the transfer was that the eclectic mix of drawer and cabinet sizes in the Vertebrate Store meant the order of the collections had to be disturbed when transferring to the standardised cabinets of the new store, resulting in a further project post-redevelopment.

By the middle of December 2014, the majority of the collections had been moved, with the remaining time available to move furniture and equipment, and to ensure the safety of the larger specimens left in the gallery. Perhaps the most difficult part of the transfer was the ethical disposal of the Museum's old cabinets,

especially from the Bird Room. Offers to museums regionally and nationwide had limited success (few had the space for such large cabinets), but eventually an antiques dealer was found, who took the cabinets for use in a showroom. No cabinets of monetary or historical value were sent to landfill. The mid-January 2015 deadline to move the collections was achieved with a day to spare (Figure 6), enough time to plan a celebration for all in the near-empty Museum gallery.

Discussion

The collections team faced an enormous challenge to achieve a safe collections move within the timeframe, but did so thanks to a time and motion study being laid out at the beginning of the project, the resources required being made clear, and an ambitious volunteer programme that provided the people needed when we needed them most.

But achieving the collections move would have been only a partial victory had it occurred without taking advantage of the situation itself. Packing the collections in their entirety creates a much better working knowledge of the collections, for the Collections Manager especially, resulting in lost specimens being relocated and even a few surprises turning up (such as a preserved thylacine stomach in a box! (Sleightholme and Campbell, 2017)).

Perhaps the greatest improvement the Museum has made as a result of the redevelopment has been a cultural change. The desire to improve our collections care and to train staff and volunteers in professional packing methods meant we could justify the employment of conservation staff on the team for the first time. This has fundamentally altered how staff care for and work with the collections. Having a conservator on-hand to advise, guide, and monitor the move and the stores, gallery, and labs has been crucial.

We took advantage of the packing (and unpacking) phase by conducting audits and conservation surveys. Although time was limited to act upon the results of this, the information generated will inform our future collections care and conservation plan. The realisation of the conservation needs of the collections, coupled with a better understanding of how a conservator role fits into the Museum, has prompted a staff restructure that caused a temporary role to be made permanent post-redevelopment.

The successful volunteering programme initiated at the Museum has continued, with half a dozen of the first cohort of volunteers still routinely working alongside staff four years later. In fact, the Museum has not had been required to recruit new collections volunteers since March 2014, such is their dedication to the project. The volunteering programme has also attracted interest from a number of nearby museums who are also going through a collections move, and for which UMZC has been keen to provide advice.

Measuring the volume of the collections prior to the move was a necessity, but also a good opportunity to make efficient use of the new space provided, and it demonstrated the need for increased storage capacity as we move forward. This has proven prescient, as no sooner than we began moving the spirit collections back into their refurbished store, the Museum was offered a substantial donation of Lake Malawi fishes, which we simply would not have been able to acquire had we not advocated for increased storage capacity in the form of roller-racking in a previously statically-shelved storeroom. However, the rush to move the collections within the 14-week period has resulted in a certain amount of disorder in the stores, particularly the Vertebrate Store, which will require significant time to rectify. This was unfortunate, and an argument was made for more time for the moving phase, but with multiple-stake holders awaiting the beginning of Phase Two, there was no room in the schedule. The 14-week move schedule also meant we had limited opportunity to isolate and freeze the entire collections before they moved into their new locations. The most vulnerable specimens were prioritised for freezing, and some specimens were double-wrapped to be frozen later.

Working within a building site also came with significant challenges, which could easily be the subject of a further series of papers. Constant vigilance to combat the risk to collections through leaks caused by burst pipes, the use of hoses to remove dirt in floors above the Museum, and rainwater finding its way through temporary roofs slowed the project and sapped the energy of the Collections team. Over the packing period, some 62 leaks as well as other disruptive incidents (such as dust pouring into the gallery space, alarm malfunctions, and power cuts) all took their toll; thankfully, the collections came though the move relatively unscathed due to the excellent packing techniques employed by our staff and volunteers, a well-stocked and constantly restocked disaster kit, and the quick responses of the Museum team and University Security, who were always willing to conduct out-of-hours patrols.

The opportunity to share the experience of the collections move via Facebook, Twitter (@ZoologyMuseum), conferences, and local news raised the Museum's profile and encouraged us to engage more with the Zoology Department, University, and the wider museum world, culminating in hosting the 2017 conference and AGM of the Natural Sciences Collections Association (NatSCA). Indeed, one of the local news journalists covering the Museum's project was impressed enough that she has volunteered for the past three years, not only helping with the collections but also providing sound media advice.

Lastly, and as realised by countless museum professionals the world over, a move of this kind is one of the most stressful and challenging periods of one's career. It is of crucial importance for the team to pull together, to look out for one another, and celebrate as many successes as possible. A collections move of this kind is not done every day, or indeed every decade, and each one is unique – in each case, there is a lot to learn along the way, and the Author is confident that other museums have alternate and equally ingenious solutions to their particular collections move.

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The Cole Museum of Zoology: A brief history as it faces a new beginning

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Abstract

The Cole Museum of Zoology (REDCZ) at the University of Reading was founded in the early 20th century by Professor Francis Joseph Cole. Comparative animal anatomy is the principal scientific focus of the collection, represented by taxidermy, skeletons, histological preparations, fluid-preserved dissections, fossil material, casts, and some superb models of developmental stages. Overall, the collection contains over 3,200 fluid-preserved and dry specimens in addition to many hundreds of specimens in satellite collections used for teaching (approximately 38,000 specimens in total). More than 50% of the specimens are vertebrates, which reflects both Professor Cole's research interests and the need to illustrate a curriculum that was heavily focused on vertebrates. Cole was an important figure in early 20th century zoology and became a Fellow of the Royal Society of London. He was the driving force behind zoology at the University of Reading, and it is a testament to his vision that we still teach BSc Zoology using his collection. The museum is currently housed in its third home, but after just under 50 years in one spot, 2019 will see it moved to a new Health and Life Sciences building as an integral part of the entrance foyer. It is hoped that 2019 will herald a new era for the museum, beginning on the journey towards a 200 year history at the University.

Keywords: Francis Joseph Cole, University of Reading; REDCZ

Introduction to Francis Cole and overview of the collection

The Cole Museum of Zoology (REDCZ) at the University of Reading was founded in the early 20th century by Professor Francis Joseph Cole F. R. S. (1872 - 1959) (Figure 1). The exact date of this foundation depends on criteria applied. Many European museums have sketchy information on which to attribute their foundation, and dates may be deduced from the publication of the first catalogue or the birth or death of the founder (Cole, 1944). Ten years ago (in 2007) we celebrated the museum's centenary, attributing the foundation to the date of Professor Cole's promotion to the Chair of Zoology at the University of Reading. However, with further consideration, it would be more accurate if the official foundation coincided with the first entry into the accession catalogue, in 1909.

By modern standards, Cole had an unusual route into academia. Although he started his working life as a journalist, Cole was passionate about zoology, attending classes and studying textbooks in his spare time (Franklin, 1960). In 1892, Cole was engaged as an

apprentice under the supervision of James Cossar Ewart, Professor of Natural History at Edinburgh University (Franklin, 1960). Under Cossar Ewart's tutelage he produced a number of fish anatomy papers, including one on the nervous system of *Chimaera* Linnaeus, 1758 (Cole, 1896). Although he had no formal qualification, Cole's obvious academic aptitude, and years of tuition under a number of eminent Professors of zoology, won him a lectureship at Liverpool University College in 1894 (Eales, 1959). During the tenure of his lectureship, Cole pursued a BSc by research at Oxford, and his undergraduate research won him the Rolleston Memorial Prize for his work on the cranial nerves of *Chimaera* (Eales, 1959; Franklin, 1960). In 1906, Cole was appointed to a lectureship in zoology at University College, Reading (later the University of Reading), and in 1907 became the first occupant of the Chair of Zoology. Cole was dedicated to education, and passionate about teaching animal diversity and anatomy. He went on to win the Neill Gold Medal and Prize of the Royal Society of Edinburgh in 1908 for his work on myxinoid fish (hagfish) (Cole, 1926), and received his DSc from Oxford in 1910 (Franklin, 1960). In 1926, he was elected to the Fellowship of the Royal Society of London (Franklin, 1960).

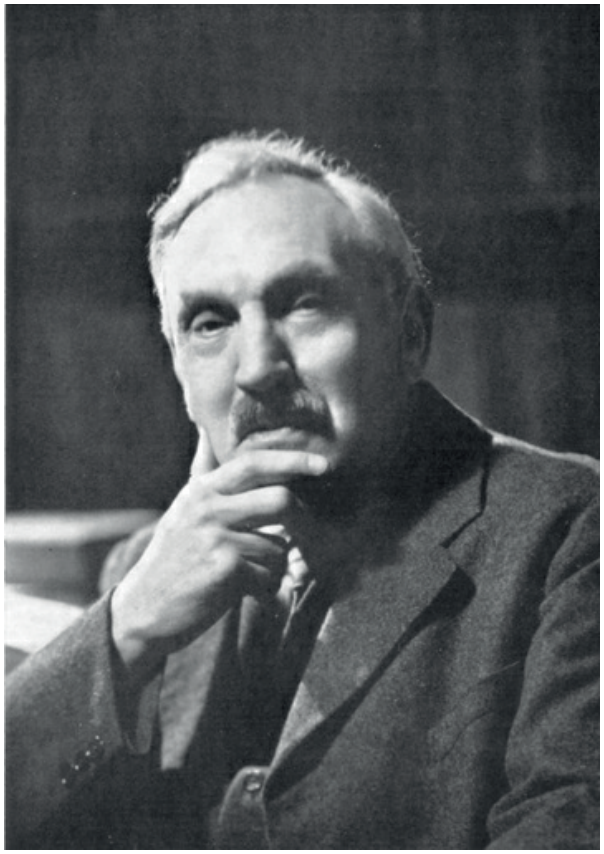

Figure 1. Professor Francis Cole. Image: Howard Coster.

Cole's museum was twice recognised nationally for its value, scientifically and historically. In 1939, on the occasion of Cole's retirement, the scientific journal *Nature* described the Cole Museum as "*being without a rival*" among its modern contemporaries (Anon., 1939). The University of Reading Council recognised Cole's contribution and resolved that "*the Zoological Museum, which is his creation, will remain as a permanent memorial of the professorship which he has held for thirty-three years in the University College and University of Reading*" (University of Reading Council, 1939). The Council further resolved that the Zoological Museum should henceforth be known as 'The Cole Zoological Museum' (Ibid.), although it has always since been referred to as The Cole Museum of Zoology.

In addition to his zoological collection, Cole, a lifetime bibliophile, assembled an impressive collection of books, which he used as sources when writing his own book on comparative anatomy (Cole, 1944). The Cole Library contains 8,000 works on anatomy and zoology, including many first editions bought by Cole from his own finances. Among the most prized of these volumes are: a first edition of Darwin's *Origin of Species* (1859), a first edition facsimile of Pliny's *Natural History* (1472), and a first edition of Linnaeus' *Systema Naturae* (1735). There are an estimated 1,700 or more pre-1851 works, including many continental books. The University bought the collection in 1959. It is housed in the University of Reading Special Collections archive and can be viewed by appointment.

Such was Cole's influence that, on the occasion of the 50th anniversary of Cole's arrival at Reading, *Nature* published another short piece on the Museum (Anon., 1956). The article praised the Museum, and went on to say that it was particularly important since the Museum of the Royal College of Surgeons, considered to be "*Reading's nearest parallel and exemplar*", had been severely damaged in WWII. It also described Cole's collection as one of the finest teaching museums in the country (Anon., 1956).

Long after his retirement in 1939, in March 1955 Cole entered into a memorandum fight with the University Council and new Head of Department, Professor Alistair Graham, over the interpretation of the statute that the Museum should "*remain as a permanent memorial of* [his] *professorship*" (Cole, 1955). Cole believed the statute meant that the museum should remain static, as he had left it, with every specimen on display in cabinets for students to view. Professor

Graham took a different view, and moved some specimens out of the display cabinets to make the museum more accessible. They were placed in an adjacent room, where they were still available to view, but to Cole this was no less than the destruction of the Museum. It is interesting that the 1956 *Nature* article was published around the time that this bitter argument occurred. The amount of detail on collecting given in the article, and the fact that it was written anonymously, does raise the question of whether someone wrote it at Cole's behest. Ultimately, Cole lost the argument, and he died only three years later.

Overview of the collection

Comparative anatomy is the principal scientific focus of the Cole Museum collection, represented by skeletons, histological preparations, fluid-preserved dissections, fossil material, casts, and some superb models of developmental stages executed in-house. The Museum is relatively small, with only 3,225 accessioned specimens, and is primarily a teaching collection stored in teaching laboratories, with around 400 specimens on display to the public. The Museum is housed in the School of Biological Sciences (SBS), and is still central to zoology teaching. Teaching is supported by a multitude of non-accessioned fluid-preserved specimens that are contemporary to the collection but are stored in jars that can easily be accessed for teaching. In addition to the Cole Museum, SBS has a number of zoological collections including an entomology collection, the Wise butterfly collection, a commissioned cabinet of insects of economic importance by photographer Harold Bastin, a large mollusc collection rescued from the Accrington Museum in Yorkshire, a small British bird egg collection, a skull collection, and the surviving fossil collection from the old Geology Department at the University. The School has an excellent zoological teaching slide collection, including many slides prepared by Professor Cole, which he donated to the cash-strapped zoology department on his arrival from the University of Liverpool. These are still used in teaching.

The accessioned collection contains more than 2,000 fluid-preserved specimens that are between 60 and 100 years old. These specimens are stored in various preservatives including alcohol, formaldehyde, paraffin, and glycerol, inside glass battery display jars with flat lids with different types of sealants, such as gelatine, silicone, and bitumen. Many of the fluid-preserved specimens are animal dissections, including injections of blood vessels, lymphatics, and air sacs. The remainder of the collection are dry specimens, either air dried, taxidermy, fossil, models, bones or shells, etc. Dr David Tompsett (1910 - 1991) was a former student of Cole's who went on to work at the Museum of the Royal College of Surgeons. There, he developed a technique to produce resin casts of pulmonary vessels, and presented a number of these to the Cole Museum, including Marco resin casts of the pulmonary vessels and bronchi of a sheep, which are still used in teaching today (Anon, 1956; Alberti, 2013).

Collection and acquisition

Professor Cole began collecting zoological specimens after the University College had moved to the London Road site in Reading in 1907. At the time there were only a handful of students and the department was small, with only one lecture room, two laboratories, an office, and a workshop (Holt, 1977). Even by 1926, when the University received its charter, the museum and the degree was staffed by only Professor Cole, Dr Nellie Eales, and Mr Bill Stoneman (Padley, 1963). In 1909, Cole began the painstaking task of producing a catalogue of the museum specimens, all written by hand. The first entry is a relatively uninspiring larva of the wood leopard moth inside a cherry stem. It is not clear on what basis specimens were accessioned in the order that they appear in the register. Numbers 13-16 go from a sea urchin to a field vole, a spotted millipede, and the wonderfully unpleasant "*itch mite on a scaly leg*". Luckily, we have a richness of records from that period, with pre-accession catalogue notebooks and lists, notes on the purchase of material, and two types of card index (organised alphabetically and taxonomically). The handwritten accession catalogue is available online via the University Library collections catalogue, Enterprise. As well as containing detailed descriptions of specimens, the accession catalogue is, in places, illustrated with extremely detailed anatomical drawings to help with interpretation of the specimens (Figure 2). Unfortunately, there is often relatively poor information on the geographic origin of material and dates of collection, which limits the use of specimens in modern research. Cole was very much of the opinion that the collection was for zoological instruction, stating "*the function of our museum is a matter of much educational importance. It only has a minor and incidental connection with research …*" (Cole, 1955).

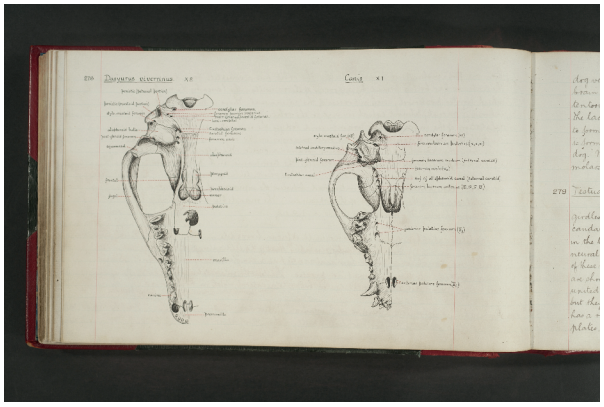

Figure 2. Sketch of specimen REDCZ-COLE278 Dasyurus viverrinus (Shaw, 1800) (Eastern Quoll) to compare the skull with that of a dog. Image: University of Reading.

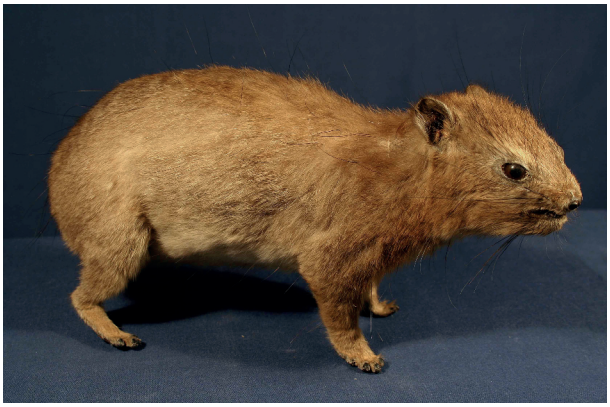

Figure 3. Hyrax (Procavia capensis Huxley, 1869) from Janganyika (REDCZ-COLE3064), stuffed by Edward Gerrard & Sons, Taxidermists and donated by Eric Burtt in 1930s. Image: Cole Museum of Zoology.

The museum has quite an eclectic mix of specimens from throughout the world, thanks to Cole's pro-active methods of acquisition (preferably for free). Cole produced a bucket list of specimens according to his plans, and tasked his many friends to find them. African game wardens, visiting scientists, and zoologists worldwide were all asked to contribute, and specimens were donated by the Natural History Museum of London. Specimens were also donated by admirers, including a flying phalanger (*Petaurus* Shaw, 1791; REDCZ-COLE590) from the Australian government. Professor Isao Ijima, Director of the Misaki Marine Biological Station, University of Tokyo (1904 - 1921) donated many marine specimens to the Cole Museum, including two giant spider crabs (*Macrocheira kaempferi* (Temminck, 1836)); REDCZ-COLE648, REDCZ-COLE651) and a number of beautifully prepared sponges. He went to considerable trouble to help Cole, dredging the ocean no fewer than six times to finally acquire a *Metacrinus rotundus* Carpenter, 1885 sea lily (REDCZ-COLE819), a type of echinoderm (Anon., 1956). Cole was lucky to obtain an enormous *Python curtus* Schlegel, 1872 with 163 pairs of ribs (REDZ-COLE1692) and an orangutan skeleton (REDCZ-COLE783) from Dr Hanitsch, a former director of the Raffles Museum in Singapore (Anon., 1956). An unnamed officer of an Antarctic whaling ship donated a series of specimens to illustrate the auditory organs of a rorqual whale (REDCZ-COLE3020).

In his memoirs, Fred Padley recorded that Cole frequently came back from visiting other universities with a specimen under his arm (Padley, 1963). Former students who had taken posts abroad were asked to collect and donate specimens of exotic animals, and thanks to them the Cole Museum has lemurs and tenrecs from Mauritius (donated by Dr Scott Cowper), a manatee from Sierra Leone, and an African hyrax (*Procavia capensis* Huxley, 1869; REDCZ-COLE3064) (Figure 5), to name a few. Details of all the Cole specimens plus photographs of some specimens can be found online through the University of Reading library (Enterprise search http://www.reading.ac.uk/library/).

This approach to developing the museum continued beyond Cole's era. In 1951, Rex Cowper graduated from Reading with a degree in zoology and took up an appointment with the CSIRO Division of Fisheries in Tasmania. Before leaving the department, he promised Dr Nelly Eales that he would send the Cole Museum a specimen of the rare Australian Leafy Sea Dragon (*Phycodurus eques* (Günther, 1865)), if he was lucky enough to find one. 14 years later, a colleague of his, working in the Western Australian fishing port of Albany, was approached by tourists who had caught a strange fish whilst snorkelling; it was a Leafy Sea Dragon. Since many of Rex's colleagues knew of his long quest to find a Dragon, they knew immediately who to send it to, and Rex passed it on to Nelly at Reading. Until 2007, when in his 80s, Rex didn't know if his Dragon had survived the ravages of time - or indeed the journey to Reading - since he had no acknowledgement of receipt. Luckily, he was still receiving and reading the University of Reading alumni magazine, which featured the specimen on the front page to celebrate the centenary of the museum. He emailed immediately to say how thrilled he was to find that the Dragon was still in perfect condition and was on permanent display in the museum: "*I'd almost forgotten what a beautiful creature*

Figure 4. The leafy sea dragon Phycodurus eques (Günther, 1865) REDCZ-COLE3206. Image: Cole Museum of Zoology.

it was when I set eyes on it for the very first time more than 40 or so years ago" (Cowper, 2007). (Figure 4).

Specimens in early 20th century teaching

The Cole Museum display area is currently organised around taxonomy and animal diversity, and is still an important resource for undergraduate teaching. For Cole, the function of the museum was to supplement the lectures by "*awakening a more curious and scholarly interest in the subject*" (Cole, 1955). However, it does not cover the entirety of animal diversity: of the 32-35 animal phyla currently recognised (depending on the source you use), only 24 modern phyla are represented in the collection (Hejnol and Dunn, 2016). Some six modern phyla were only discovered and described after Cole retired, and specimens have not been acquired by any recent curators (Table 1). According to the 1933 BSc syllabus, animals were organised into 11 phyla, with the first comprising Protozoa (four accessioned specimens), which are no longer considered to be closely related to multicellular animals. Molecular taxonomists have rearranged our understanding of animal relationships in the past 50 years, and no doubt will continue to do so. Since Cole's time, many animal groups have been elevated to phyla: e.g. the Phyla Sipuncula and Echiura were originally described as classes within Annulata, along with annelid worms. However, recent understanding has reverted some taxonomic groups back to the 1933 groupings recorded: Sipuncula and Echiura are now in the Phylum Annelida, along with annelid worms (Struck et al., 2007) (Table 1).

Phyla unrepresented in the Cole Museum are microscopic, and there are no microscope slides accessioned into the museum. However, one of our satellite collections holds some 25,000 slides, many of which were prepared by Cole himself. This collection is being catalogued by volunteers. The slide collection includes marine invertebrate larval specimens collected on zoology field courses in Port Erin, Isle of Man, by H. Chadwick. These specimens were used by W. Rogers, the laboratory technician, to prepare wax models for the museum (Anon., 1956).

As with the museum, in which 51% of the specimens are chordates (most of which are vertebrates), half of the microscope slides are of chordate material. Although chordates represent less than 5% of animal species on the planet, much of the teaching and research in Cole's era concentrated on this group.

Over 96% of the museum collection comprises animals from the so-called 'Big 9' (see Table 1), which represent the most speciose animal phyla, aligning to a curriculum based heavily on these animals. Indeed, the 1933 BSc Zoology syllabus was basically a list of animal phyla, orders, and families, with notes on which specimens to use and how to prepare them. Teaching would have been undertaken with non-accessioned specimens, and Cole was strongly of the opinion that his museum was not for use in class. He had a fairly romantic view of his collection, and went on to say that the museum "*adorns the nakedness of truth, and alleviates the harshness of instruction*" (Cole, 1955). This poetic view of the museum implies that lectures were rather dull. However, it is thanks to this approach that we have a wealth of specimens that are contemporary to the museum specimens. We do use his specimens in classes now, since the display museum is only a small percentage of the collection.

Table 1. List of animal phyla and number of specimens in the Cole Museum of Zoology and other collections held by the Museum (all numbers represent single items or containers and do not take number of specimens into account). In 1933, only 11 animal phyla were recognised in the syllabus (in bold). [1]Struck et al., 2007

Phylum	Cole	Other Collections	Total	Notes
Acanthocephala	7	0	7	Now thought to be in Phylum Rotifera. Listed in 1933 syllabus as a Class in Phylum Nemathelminthes.
Annelida	107	63	170	One of the 'Big 9' phyla. Listed in 1933 syllabus as Class Chaetopoda in Phylum Annulata.
Arthropoda	578	4671	5249	One of the big 9.
Brachiopoda	32	311	343	Listed in 1933 syllabus as a Class in Phylum Molluscoida.
Bryozoa	18	49	67	Listed in 1933 syllabus as a Class in Phylum Molluscoida.
Chaetognatha	2	3	5	Listed in 1933 syllabus as a Class in Phylum Nemathelminthes.
Chordata	1681	465	2146	One of the big 9.
Cnidaria	198	287	375	One of the big 9. Placed in Phylum **Coelenterata**.
Ctenophora	7	3	10	Not recognised as a Phylum in 1933. Placed in Phylum **Coelenterata**.
Cycliophora	0	0	0	None in collection, discovered in 1995. Microscopic.
Echinodermata	139	250	389	One of the big 9.
Echiura	3	0	3	Until very recently its own Phylum, but now a subphylum in Phylum Annelida[1]. Referred to in the 1933 syllabus as Class Echiuroidea in Phylum Annulata.
Entoprocta	1	0	1	Listed in 1933 syllabus as a sub-class in Phylum Molluscoida.
Gastrotricha	0	0	0	Microscopic. Listed in 1933 syllabus as a Class in Phylum Trochelminthes.
Gnathostomulida	0	0	0	None in collection, discovered in 1956.
Hemichordata	9	76	85	Listed in 1933 syllabus as a Class in Phylum Chordata.
Kinorhyncha	0	0	0	Microscopic.
Loricifera	0	0	0	None in collection, discovered in 1983.
Micrognathozoa	0	0	0	None in collection, discovered in 1994.
Mollusca	310	3874	4184	One of the big 9.
Nematoda	19	40	59	One of the big 9. Listed in 1933 syllabus as a Class in Phylum Nemathelminthes.
Nematomorpha	1	0	1	Listed in 1933 syllabus as an Order Gordionidea in Phylum Nemathelminthes.
Nemertea	14	4	18	Listed in 1933 syllabus as a Class Nemertinea in Phylum Nemathelminthes.
Onychophora	8	0	8	Listed in 1933 syllabus as Class Onycophora in Phylum Arthropoda.
Orthonecida	0	0	0	Microscopic.
Placozoa	0	0	0	Described in 1971.

Platyhelminthes	63	37	100	One of the big 9.
Phoronida	2	6	8	Listed in 1933 syllabus as a query as to its status as phylum or class.
Porifera	77	141	218	One of the big 9.
Priapulida	1	0	1	Listed in 1935 syllabus as Class Priapuloidia in **Phylum Annulata.**
Rhombozoa	0	0	0	Microscopic parasite.
Rotifera	0	0	0	Listed in 1933 syllabus as a Class in Phylum Trochelminthes.
Sipuncula	6	5	11	Until very recently its own Phylum, but now a subphylum in Phylum Annelida[1]. Listed in 1933 syllabus as Class Sipunculoidea in Phylum Annulata.
Tardigrada	0	0	0	Microscopic.
Xenoacoelomorpha	0	0	0	Formed from Xenoturbellida (described in 1946) and Acoelomorpha (described in 1949).
TOTAL	**3286**	**10285**	**13571**	

Maintaining the collection

For the first 50 years of its existence, the Cole Museum was run by technical staff who developed national expertise in specimen preparation and conservation. Former curator Bill Stoneman prepared transparencies of bones and cartilage, stained to show skeletal parts *in situ* (Figure 5). Laboratory technician Bill Rogers produced wax models of invertebrate larvae, and technician Fred Padley MBE published on making cheap glass covers for specimens, and on the mounting of wet specimens in the museum (Padley, 1933; 1935). When the museum moved with the zoology department from the London Road campus to a new, purpose-built home on the Whiteknights campus in the 1970s, the move was undertaken by the technical staff with help from students. As soon as the Spring term had finished on 18th March 1971, the task of moving the Cole Museum began. The elephant skeleton (REDCZ-COLE1150) was dismantled two days later. The elephant's spinal column, with its steel supporting bar, was carried on the shoulders of students up Redlands Road to the new building (Snowden, 2017). It took three months just to move the museum out of London Road, and time ran out before term began in the Autumn to think about reassembly. This resulted in the storage of the elephant and other skeletons on the roof of the building under quickly built shelters. Unfortunately, they remained there for a further two years and suffered somewhat from the weather (Snowden, 2017).

Staff had no conservation training, but did a fantastic job of reassembling the elephant from photographs. The skeleton had originally been articulated and displayed by driving spikes up the long bones of the legs; by the 1980s, the skeleton was listing and the spikes were beginning to push through the side of the leg bones. The chief technician, Edward Snowden, took it upon himself to dismantle the skeleton, and welded a tubular steel framework to suspend it and

Figure 5. Chameleon preparation REDCZ-COLE2962. Image: Cole Museum of Zoology.

take the weight off the legs (Snowden, 2017). Over the years, the ex-circus elephant, Norman, migrated from position to position - and even appeared on BBC TV for the Open University – but, gradually, the new cases and some of the specimens began to show their age. Some specimens migrated from the museum without records to track their location, some were stolen (including REDCZ-COLE1088, a manatee skull taken from the skeleton, and REDCZ-COLE1229, a whole tuatara skeleton from the display area (1990s and 1960s respectively)), some were damaged, and little effort was given to maintaining fluid-preserved specimens in storage if they were not used in teaching.

In 2003, a group of zoologists decided to take advantage of funding available from the Arts and Humanities Research Board (AHRB) and, together with funding from the Friends of the University of Reading, undertook a complete refurbishment of the cases. Dr Steve Hopkin, the curator at the time, redesigned the display in taxonomic order to show the diversity of the animal kingdom. In 2005, I took over from Steve as the academic curator of the collection. A conservation programme had already begun, to ensure that the display specimens were in good order. Specimens in storage were another matter. The fluid-preserved specimens were stored in an adequate outhouse, but many required a great deal of conservation. Many of the dry specimens were stacked haphazardly in unlocked cupboards in the foyer and labs, or in academic offices, for ease of use in teaching. Some were even on display in other Departments, following academics who had moved into new areas. My first task was to round up everything we could find and convince staff that they did not own specimens they habitually used in teaching or had 'borrowed'. This was followed by an audit, production of a digital catalogue, improved storage, and the writing of professional documentation.

With funding from the Higher Education Funding Council for England (HEFCE) under their Centres for Excellence in Teaching and Learning (CETL) programme and the Arts and Humanities Research Council, we launched several new projects within the Cole Museum, including a fluid specimen conservation project and an electronic guide to the Museum. Funding also allowed the development of new cases, and the training of technical staff who went on to train undergraduate students in the specialist techniques needed to maintain and restore a natural history collection. In 2010, the museum was accredited by the Museums and Libraries Association, and in 2015 by Arts Council England.

Housing the Museum and the next 100 years

The Museum was originally based on the London Road campus of the University (Figure 6). After Cole's retirement in 1939, space was an issue. After a delay due to the outbreak of World War II, a new zoology building was completed at the London Road site, with basements that could double as air-raid shelters. The aforementioned 1956 *Nature* article on Professor Cole and his Museum noted that the Museum was housed in an inadequate building, stating that "*it is greatly to be hoped that on the new University site…*" (the Whiteknights campus purchased in 1946) "*…a worthy building will be planned*", and also that the University would make sure that it maintained "*what is a unique asset, not only for the University of Reading, but also for the entire country*" (Anon., 1956).

Figure 6. The Cole Museum at the London Road site. Image: Cole Museum of Zoology.

It was not until 1971, some 15 years later, that a new building was finally available to move the Museum. This building was built to house not only Zoology but also the new Physiology and Biochemistry department. With an eight-floor tower making it the highest building in the area, it was originally known as the PBZ Building, but since 1992, when the School of Animal and Microbial Sciences (AMS) was created, it has been known as the AMS building. AMS was amalgamated with Plant Sciences and Statistics in 2006 to create a large School of Biological Sciences. The AMS building, which has housed the Cole Museum for 46 years, was vacated by Biological Sciences in 2008, leaving only the teaching labs and Museum in place underneath a ghost tower. There were no existing plans to re-house the museum, which suddenly faced an uncertain and worrying future. The years ticked on and no plans emerged.

This isolation resulted in a blanket of peace descending (when school groups were not visiting), and our external visitor numbers rose, helped by social media and online advertising. This pause has been fortuitous. There has been a recent renewed interest in collections within the University, plus an acknowledged need for a new building for Biological Sciences. In the past few years, the University of Reading has developed Heritage and Creativity as one of its major research themes, and the collections (the University has many, including two other accredited museums) have a new value.

The next stage of the Museum's history has just begun. In 2019, the Cole Museum will move into a new building for Health and Life Sciences, in a section of the foyer specifically designed to house it. It will be an important element of the new building, forming the entrance to the laboratories and upper floors, and represents a significant investment by the University. It will be the 110th anniversary of the official start of the accession catalogue in 1909. I like to think that Professor Cole would be pleased to know that his collection is still valued and cared for, and will have a place in the future of the School and University. However, I suspect that he would not approve of my plans to put many specimens into storage in another building.

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NatSCA 2017 AGM Minutes

Thursday 20 April 2017
University Museum of Zoology, Cambridge
14:20 - 15:00

Agenda

Attendees: Paolo Viscardi (PV), David Gelsthorpe (DG), Jan Freedman (JF), Miranda Lowe (ML), Roberto Portela Miguez (RPM), Paul Brown (PB), Jack Ashby (JA), Maggie Reilly (MR), Clare Brown (CB), Rachel Jennings (RJ), and Isla Gladstone (IG).

1. Apologies for absence

Vicky Purewal (VP), Holly Morgenroth (HM), Donna Young (DY).

2. Minutes of AGM held on Thursday 21 April 2016, The Silk Mill & Derby Museum

Held at the Silk Mill and Derby Museum, as published in *Journal of Natural Science Collections*.

There were no issues raised by members at the meeting. These were signed as a correct record of that meeting by the chair.

Proposed: Anthony Roach Seconded: Glenn Roadley

3. Chairman's Report

This past year NatSCA has been actively involved in helping coordinate with other Subject Specialist Networks(SSNs) in an effort to present a more unified front in addressing common issues arising in the museum sector. This has resulted in a feature in the Museums Journal and a panel session at the Museums Association 2016 conference. NatSCA also had a presence at the Collections Trust Conference, where we talked about Natural History Near You and mechanisms for communicating within the sector.

Our AGM, which focused on how natural science collections inspire our connection to the natural world was hosted by the Silk Mill and Derby Museum & Art Gallery and was attended by over 100 delegates. Evaluation suggests that attendees found it an overwhelmingly useful and enjoyable event. We noticed that there has been an increase in first-time attendees, which matches against our increase in new members. It's great to see the membership grow and we hope this will encourage greater sharing of experience, allow for some fresh ideas and give us a stronger voice when advocating for collections.

Two organisations were successful in applying for the 2016 Bill Pettit Memorial Award, the Museum of Life Sciences, King's College London and the Herbert Art Gallery and Museum. It was heartening to see that natural science collections are being successfully integrated with social history and art, helping to demonstrate how nature is an integral part of culture.

Our training offer this year had a somewhat legal slant. In January we worked with colleagues in the Society for Museum Archaelogy and Museum Ethnographers Group to deliver a Curating Human Remains in the UK seminar, and we collaborated with the South West Area of Natural Science Collections to deliver a joint Natural Science and the Law seminar in June. We have also been working closely with the Geological Curators Group to develop a joint project to create a mechanism for skills sharing using videos and a wiki. So far, we have not been able to secure funding to aid the delivery of this, but the process is ongoing and over £50,000 of waived location fees and staff time have been offered by museums around the UK to support the project.

Finally, the chair of NatSCA, Paolo Viscardi, would like to offer heartfelt thanks to the whole of the NatSCA committee and our team of excellent volunteers: Justine Aw, Glenn Roadley, Gina Allnatt, Emma-Louise Nicholls, Sam Barnett, David Notton, and Lee Davies. Special thanks to our treasurer Holly Morgenroth, who plays an absolutely vital role in everything we do.

4. Treasurer's report

CHARITY COMMISSION FOR ENGLAND AND WALES

Natural Sciences Collections Association			1098156
Receipts and payments accounts			**CC16a**
For the period from	01.02.2016	**To**	31.01.2017

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	2,230	-	-	2,230	1,721
Personal subscriptions	3,533	-	-	3,533	3,822
Workshops	885	-	-	885	5,430
Conferences	10,678	-	-	10,678	7,114
ACE Grant - Network Improvement Project	-	-	-	-	1,400
Bank Interest	7	-	-	7	7
	-	-	-	-	-
	-	-	-	-	-
Sub total*(Gross income for AR)*	17,333	-	-	17,333	19,494
A2 Asset and investment sales, (see table).					
	-	-	-	-	
Sub total	-	-	-	-	-
Total receipts	17,333	-	-	17,333	19,494
A3 Payments					
Running costs	2,177	-	-	2,177	1,772
Workshops	863	-	-	863	1,880
Conferences	6,546	-	-	6,546	5,453
Publications & Information provision	1,896	-	-	1,896	2,017
Bill Pettit Memorial Fund	1,500	-	-	1,500	1,500
ACE Grant - Network Improvement Project	149	-	-	149	1,799
Bursaries	373	-	-	373	185
Other	37	-	-	37	73
Sub total	13,541	-	-	13,541	14,679

A4 Asset and investment purchases, (see table)					
	-	-	-	-	
	-	-	-	-	
Sub total	-	-	-	-	-
Total payments	13,541	-	-	13,541	14,679
Net of receipts/(payments)	3,792	-	-	3,792	4,815
A5 Transfers between funds	-	-	-	-	-
A6 Cash funds last year end	24,344	-	-	24,344	19,529
Cash funds this year end	28,136	-	-	28,136	24,344

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		28,136	-	-
		-	-	-
		-	-	-
	Total cash funds	28,136	-	-
	(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	conference invoice	60	-	-
		-	-	-
		-	-	-
		-	-	-
		-	-	-
		-	-	-

	Details	Fund to which asset belongs	Cost (optional)	Current value (optional)
B3 Investment assets			-	-
			-	-
			-	-
			-	-
			-	-

	Details	Fund to which liability relates	Amount due (optional)	When due (optional)
B5 Liabilities	committee expenses	unrestricted	410	01 March 2017
	journal 2016	unrestricted	1,891	01 March 2017
	early subsription payments for 2017	unrestricted	193	01 March 2017
			-	

Proposed: Laura McCoy Seconded: Erica McAlister

5. Membership Secretary's Report

There are 267 paid up members, breaking down as 54 institutional and 213 personal members. Over the course of the year there are an encouraging 39 new members: five institutional subs, 30 brand new members, and four returning past members. There have been four institutional resignations.

These gains, as in previous years, are counterbalanced by losses from the membership other that notified resignations. This year, all members who were more than two years in arrears with subs were deleted from the database, and the mailing list edited to reflect the deletions. The net result is a notable stability in numbers over the last several years of around 210 – 215 personal members and 50 – 55 institutional members.

There are seven hard-copy mailings required by copyright libraries and a further nine FOC mailing we maintain with key contacts, ie ACE; MA; SPHNC; GCG; Smithsonian; Zoo Record and our patrons – a number of these are supplied as electronic copies. All those members paid up by mid-January 2017 (!) should have received their hard copy 2016 journal plus the password to download articles from the on-line version.

All members should have received a reminder that 2017 subs were due at the beginning of February. Paper invoices are sent to institutional members, as payments are usually processed through Finance Offices, but institutional subs may also be paid via Paypal. Contact the membership secretary for details.

6. Editor's Report

Progress in 2016/17:

Handover meeting with previous Editor, Jan Freedman, on 24 May 2016.
Journal of Natural Science Collections Volume 4 had 13 submissions (seven were published, three rejected, two withdrawn, and one deferred to Vol. 5).
Publication of the *Journal* was delayed; it came out in February 2017.
Seven *NatSCA Notes & Comments* articles have been published online, primarily write-ups from #NatSCA2016.
New publishing software has been acquired for typesetting articles – this speeds up the process of preparing articles for publication.
Updated the *Journal*'s guidelines for authors, and created new guidelines for *Notes & Comments*, as well as guidance for reviewers of the *Journal*. These are all available online.

Plans for 2017/18:

Volume 5 of the *Journal* is due out in December 2017. Deadline for submissions to guarantee consideration is 31 July 2017.
Considering putting together an Editorial Board to assist in review process.
New volunteer/s to help proof-read and edit submissions.
Trialling Trello as a project management tool to plan and schedule production.

Thanks:

Jan Freedman and David Notton, for all their help and advice this year. Gina Allnatt and Glenn Roadley, who now manage the NatSCA Facebook page. Emma-Louise Nicholls, who manages the NatSCA blog. All the authors who have contributed to our publications, and the reviewers who generously volunteered their time and expertise.

7. Election of Ordinary Members of NatSCA Committee

Below are the nominees for NatSCA committee posts to serve from 2017 to 2019 and 2020 in the cases of the chair and the secretary which have reached the secretary. The membership secretary has checked to see that those proposed, those proposing and those seconding are all present members of NatSCA.

Post	Nominee	Institution	Proposed	Seconded
Chair 2017-2020	Paolo Viscardi	National Museum of Ireland, Dublin	Rachel Jennings	Matthew Parkes
Secretary 2017-2020	Roberto Portela Miguez	NHM, London	Claire Valentine	Paolo Viscardi
OM 2017-2019	Jack Ashby	Grant Museum of Zoology, London	Erica McAlister	Lucie Mascord
OM 2017-2019	David Gelsthorpe	Manchester Museum	Rachel Webster	Dmitri Logunov
OM 2017-2019	Miranda Lowe	NHM, London	Roberto Portela Miguez	Jo Hatton
OM 2017-2019	Isla Gladstone	Bristol City Museum	Ray Barnett	Holly Morgenroth
OM2017-2019	Lucie Mascord	Lancashire County Council	Paolo Viscardi	Patricia Francis

As there are no contested posts, no election is required. If there are no objections to the candidates, can we accept and elect the listed people en block onto committee to serve for three years for the treasurer and two years for other committee members.

Proposed: Mark Carnall Seconded: Erica McAlister

Already in post

Post	Name	Insititution
OM 2016-2018	Paul Brown	NHM, London
Membership secretary 2016-2018	Maggie Reilly	Hunterian, Glasgow
Treasurer 2016-2018	Holly Morgenroth	RAMM, Exeter
OM 2016-2018	Claire Brown	Leeds Museum
OM 2016-2018	Donna Young	World Museum, Liverpool
OM 2016-2018	Jan Freedman	Plymouth Museum
Editor 2016-2018	Rachel Jennings	Horniman Museum and Gardens, London

8. Any other business

Mark Carnall raised the issue of Human Remains Collections lacking a Subject Specialist Network.

9. Vote of thanks

PV thanked Justine Aw, Sam Barnett, Emma-Louise Nichols, David Notton, Glenn Roadley for their excellent work for NatSCA, and Donna Young, Holly Morgenroth, and the Cambridge team for organising a fantastic conference.

10. Next committee meeting

Manchester Museum, 29 June 2017, 11:00.

Meeting closed at 15:00 22/04/2017.