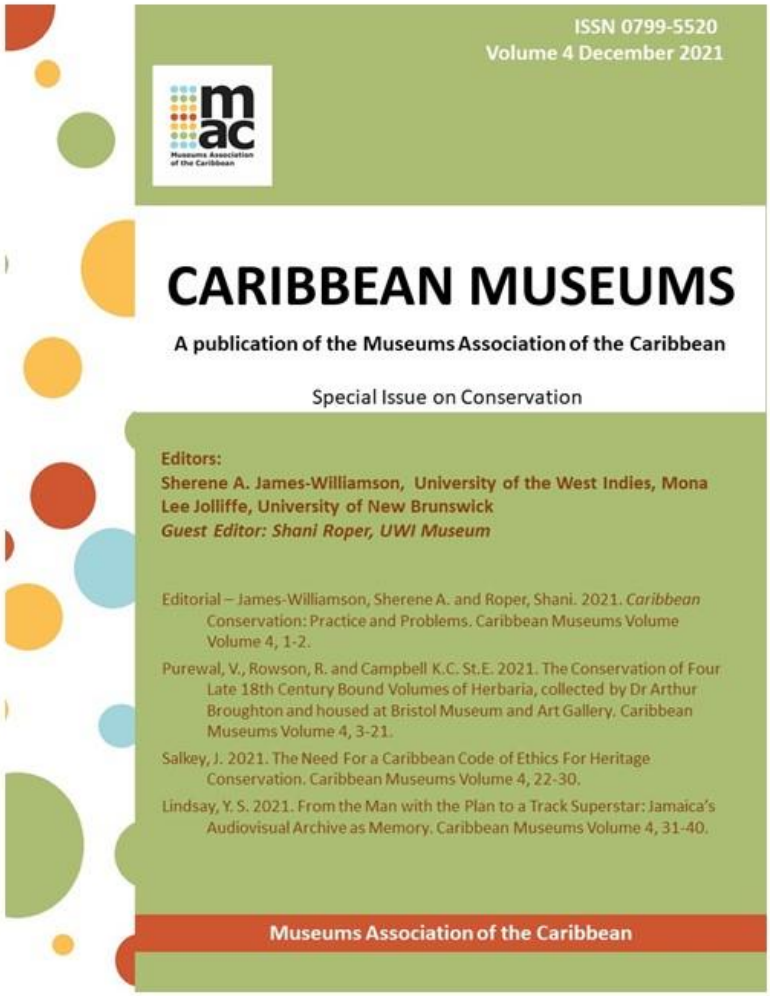

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The Conservation of Four Late 18th Century Bound Volumes of Herbaria, collected by Dr Arthur Broughton and housed at Bristol Museum and Art Gallery

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ABSTRACT. Over the past four centuries several renowned botanists have botanized and made important collections in Jamaica. These collectors include Sir Hans Sloane, Patrick Browne, Olaf Swartz, James MacFadyen, August H. R. Grisebach, William Harris, Dr. George Proctor and Dr. Arthur Broughton. Dr. Arthur Broughton collected four volumes of plants between Jamaica and Bristol in the late 1700s. Three volumes were collected in Jamaica and one from Bristol. The volumes contain type specimens and other important collections utilized by McFadyen and Fawcett & Rendle who produced early publications on the flora of Jamaica. The volumes are housed at Bristol Museum & Art Gallery (BMAG) but were in a state that was not conducive to active research because they were deteriorating and because of the techniques and toxic chemicals used for pest treatment in the past. Here we outline the steps taken to conserve these historic volumes in a way that maintains their integrity and perpetuity as well as to facilitate access through digitization for the encouragement of research.

Keywords: Arthur Broughton, Bristol, Jamaica, Conservation, Herbarium

1. Introduction

Dr Arthur Broughton bequeathed his herbarium in 1797 to the Philosophical and Literary Society of Bristol. As a boy Arthur would spend his time studying and collecting plants from the Avon Gorge, now a Site of Special Scientific Interest in Bristol with many rare species, some first recorded by Broughton. He went on to study medicine, but during Bristol's influenza epidemic of 1782, Broughton took ill. He was granted leave of absence from his post at the Bristol Infirmary and set sail to convalesce in Jamaica, where he collected and preserved the plants he found between 1786 and1796. Originally there were four volumes of Jamaican herbaria however, volume II rich in ferns, was destroyed when Bristol Museum was bombed during the Second World War. The other volumes survived because they were at the Natural History Museum, London having been studied for the Flora of Jamaica publications by Mr. William Fawcett and Dr. A.B. Rendle in the early 1920's and earlier by James MacFadyen in 1837.

In 1813 Robert Brown, the botanist and pioneering microscopist i mmortalized Broughton by naming a new genus of native West Indian orchids *Broughtonia*. The name was first given to an unidentified (at the time) *Broughtonia sanguinea* specimen that Broughton himself had collected in Jamaica. Notably, Jamaica now has three endemic *Broughtonias*, *B. sanguinea* and *B. negrilensis* and a third *B.* x *jamaicensis* which is a hybrid of the other two endemics. Other species in the genus *Broughtonia* are also found in Cuba, Bahamas, Hispaniola and Puerto Rico.
Broughton's herbarium also contains the TYPE specimens *Cassia broughtonii*

Fawcett & Rendle, 1917 = *Chamaecrista nictitans* var. *jaliscensis* (Greenm.) H. S. Irwin & Barneby, 1982 and *Portlandia*

grandiflora var. parviflora S. Moore, 1930 = *Portlandia grandiflora* Linnaeus, 1759. He also collected other Jamaican endemic species including *Lepanthes wullschlaegelii* Fawc. & Rendle and *L. ovalis* (Sw.) Fawc. & Rendle as well as *Rondeletia hirta* Sw., *Spathelia sorbifolia* L. and *Gesneria exserta* Sw. These fascinating collections are important resources for research, however the first step is the digitization and conservation of these volumes.

2. The Broughton Volumes

There are four volumes in total, one from the UK and three from the island of Jamaica where Broughton resided. Each volume comprises contemporary stationery bindings. The British herbarium is of a late 1700s stationery binding depicted by the amount of leather on the spine and corners (each variety of binding was protected by their ruling guild and one could not cross over between binding professions). Covering corners are rarely found on English bindings before the second half of the 18th century. At the end of the 18th century, small vellum corners gave way to leather, and during the 19th century the size of the corners increased to the proportions that are perhaps used to today (Middleton, 1996)

Although originally of good quality, all were made with sheep's leather which is particularly soft and does not have the strength or longevity of other leathers such as cow or goat. The volumes needed to be accessed so that the contents could be surveyed for scientific content and for conservation requirements. To access the collections meant opening the volumes and turning the pages. In all four volumes, the boards had become loose and the bindings had failed. There was also loose material, dirt and disunited labels.

The four volumes date back to the 18th century and during this period natural science collections were treated with various chemical solutions as a method of pest control. As three of the volumes were used for collating Jamaican specimens, it is anticipated that these volumes were mounted and housed in Jamaica and so biocide applications may have differed from UK treatments of the time. It was predicted that there would be residues present on the collection and that these would be stable and toxic and therefore this could affect the conservation process.

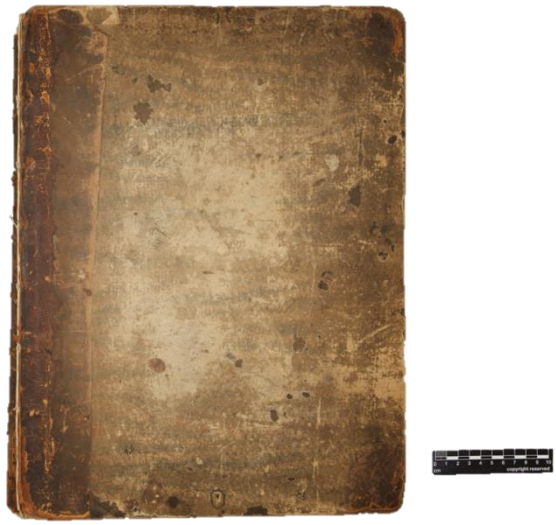

Figure 1. Photograph showing the Broughton Jamaican Volume 1

3. The Conservation Approach

As with most conservation projects, there was not one simple solution towards conserving this collection. Due to the size of the volumes and the number of specimens within, the assessment took several visits and numerous conversations with the curators at BMAG. Four main options were provided:

- To conserve the bindings and the specimens in situ
- To conserve the specimens in situ but to provide minimal

conservation to the bindings to stabilise the leather and boards to aid handling.

- To remove the specimen pages from the paper gutters by humidification and then re-mount on to herbarium sheets, with basic conservation to the volumes to stabilise, clean and re-house.
- To fully conserve the specimens by removing from the volumes and re-mounting onto herbarium sheets, with no conservation or stabilisation of the bindings

The preferred approach for both curators and conservator was the fourth option. This was cost effective, ensured that no changes were made to the original bindings and that the specimens were given priority. By re-mounting the specimens they could be incorporated into the main collections, rendering them fully accessible for study and research without excessive handling, the very opposite if they remained within the bound volumes. Damage is also limited when specimens are re-mounted onto sheets as there is no reason to invert the pages, which can cause losses and fractures to the specimens within a volume, with the turning of each page.

The specimens were believed to be of historic and scientific significance with an unknown number of rare or type specimens, however assessing the volumes was difficult as they were so unwieldy. The volumes were deteriorating, boards were detaching and they were very heavy, for example the British volume weighed 7kg and so access was limiting, without which, research and general interest would soon dwindle.

4. Initiating a Programme of Work

Once agreed, the project was divided into 9 separate phases. Below is a description of the phases and detail of the type of work involved.

Project Phases 1-9:

1) Health and safety considerations included:

- The Identification of biocides through UV scanning with a handheld UV-A lamp.
- Analysis using a handheld X-ray Fluorescing Spectrometer (XRF).
- Assessments made for appropriate Personal protective Equipment (PPE).
- Safe methods for handling and working with contaminated collections.
- Safe handling of the bound volumes that are contaminated, largely deteriorated, friable and also of considerable weight.

2) Filming of the project:

All analytical approaches were filmed but also in-depth filming was made for humidification of the specimens, re-mounting of the specimens and the introductory discussions between the conservator and the curator.

3) Conservation prior to digitization:

This was undertaken to ensure loose and surface dirt was removed to prevent transference during handling. Dirt was also removed from labels to ensure that the data was clearly legible and that the labels were in place and corresponded to the correct specimen. Loose material was placed with the correct specimen where possible.

4) Digitization of all four volumes using a DSLR camera and lights set up.

Every component of the volumes was digitized, each image was produced as a tiff image. The size of the entire number of images (1100+) did hinder the exchange process. Once BMAG were able to access the images, a number of images were chosen for selection for the ebook.

5) Data capture

Data from every label was captured, printed out and made into labels and headers for each herbarium specimen.

6) Conservation of the specimens
Each specimen was removed from the original volume using approved conservation techniques and laid onto an archival sheet. All original determination slips, or loose notes and diagrams were carried over to the new herbarium sheet, but the original handwritten information made directly onto the pages remained intact within the books and the imaged data labels were cut out and placed with the specimens.
Family folders were labelled in pencil and the corresponding genera were filed within the appropriate folders, thus aiding future access to the collection which can now be housed systematically within the herbarium.

7) Production of the eBook
The curators and the conservator selected their favourite images for inclusion in the eBook. It was agreed that only a sample selection would be made so that the size of the file was not excessive so that future storage and loading would not be problematic.

8) Boxing up of all four volumes and returning the collection to BMAG
Four boxes of archival corrugated board were purchased to house the four volumes; all of the herbarium specimens were placed into corresponding family folders and boxed for delivery to BMAG.

9) Reporting
An Interim report was also produced halfway through the project. A full report with findings and reco mmendations was prepared.

4.1. Phase 1 Health and Safety Considerations Scanning with a UV-A Lamp

The volumes were initially scanned with a handheld UV-A lamp (365nm) to establish if there were signs of mercury(I) (Hg^{+}) chloride (Hg_2Cl_2) through observation of fluorescent areas visible on the pages (Purewal, 2008). If there were positive results for mercury, Hg(I), then these observed regions are helpful in pinpointing the areas of interest for further analysis using X-ray fluorescing spectrometry. XRF is an inorganic tool applied for isolating inorganic matter within the area of interest. This is primarily a qualitative method but arsenic, mercury and lead standards were made up and the corresponding data was incorporated as a file into the instrument's programme. This provided accurate quantitative data for those three suspected elements.
The first collection analysed by UV-A lamp was the British volume. A small number of pages were scanned for mercury and the few pages scanned did not give a positive result for Hg(I) contamination. However, grey spots were present throughout the volume indicating the presence of mercuric sulphide (HgS) which meant that mercury was present in a different ionic state Hg(II), which is not detected by UV-A scanning.

Heavy metal elements such as mercury, lead and arsenic were historically applied as aqueous salts to archives, books and natural history collections. Mercuric(II) chloride was commonly applied to natural history collections, especially botanical material and the UV-A scanning technique is very proficient at isolating Mercury(I) chloride, which fluoresces. The salts reduce over time, back to the metal. The process of reducing from Hg^{2+} to Hg^{+} takes approximately 30 years. To reduce from Hg^{+} to Hg^{0} takes much longer, closer to 100 years (Purewal, 2012). With the Broughton volumes being over 200 years old, the probability that this chemical reaction has reached its conclusion is compelling. So as anticipated, the Broughton volumes provided little or no response from the scanning technique for the mercury salt.
Dark grey staining and spots were observed on the pages and this is usually

indicative of metacinnabar (HgS) (Hawks *et al. 1999*, Sirois & Helwig,1996). This does not provide a UV-A signal due to the strong bond it forms with atmospheric sulphur and so no Hg^{+} will be present.

4.2. Analysis with a handheld X-ray Fluorescing Spectrometer (XRF)

Surface XRF can be used as a semi-quantitative technique, but it is also able to identify trace amounts of key elements within the region of interest. Mercury was historically applied with other toxic metals, especially arsenic and lead, therefore XRF was an appropriate instrument to use to identify other elements and to establish the actual concentrations. After calibration, the accuracy of quantification was expected to be approximately 10%.
The instrument used was a Tracer III SD handheld XRF. The instrument was calibrated with lead, arsenic and mercury standards prior to this investigation. To increase sensitivity, the instrument was set at 40keV and a Ti-Al filter was introduced into the instrument. The methodology was maintained for instrument set up, standards calibration and sample analysis.

The results relate to the area of paper (or specimen) subjected to the X-ray beam (5.5 x 6 mm). The instrument has been calibrated to measure the concentration of metal ions within this specific area. It does not provide data on the entire sheet nor the extent of coverage of contamination across the sheet, although this could be estimated.
The pages analysed from the British volume (p131, p132 and a paper insert of later date) showed high concentrations of lead (130-447 ppm) and bromine (not calibrated) and also the presence of arsenic in lesser concentrations (20-60 ppm). The amounts were significant for the small areas analysed and so this dictated the level of protection required for safe working during conservation of the volumes.

Bromine presence was significantly high and its presence was consistent with the fact that this volume had been stored within BMAG when collections were fumed with methyl bromide. XRF provides data on all inorganic elements and can provide information on the paper composition. The modern paper example showed high titanium and calcium, iron, copper, zinc, sulphur and chlorine. Of interest is the presence of titanium as this element was only discovered in 1791, and was not detected on the original cotton papers but only on the modern papers found loose within the volumes.
The British volume did have an unusual powder present, first thought to be mould deposits. The beige powder was present sporadically throughout the volume (Figure 2). This has not been identified, as it was not noted at the time of analysis. It is most probably an organic powder, presumably lindane (ga mma-hexachorocylcohexane), a highly toxic organochlorine chemical applied as a biocide but it was also used to de-acidify pages within books. It has recently been reported to be a carcinogen (Loomis, Guyton et al. 2015).
The original bound volume paper comprised of thick cotton. This too was analysed and the composition was similar but with no titanium present.
The Jamaican volumes were then analysed to determine any difference in biocide application.

The leather covers were analysed first as these would be handled the most. Typical tanning elements were found within the leather including aluminium, calcium, chromium, iron, copper and zinc but significantly high concentrations of lead (800 ppm) and arsenic (100 ppm) were detected. No bromine was indicated.
Jamaican volume I, pages 152 and 193 were analysed. No mercury was detected

but arsenic and lead were significantly high. Arsenic readings were 1550 ppm and lead gave a similar strong peak, but no concentration value was given. XRF can produce errors when dealing with high concentrations of lead and arsenic as their x-rays overlap.

Producing standards helps to counteract this, so the instrument will provide a positive response to its presence, but the concentrations given are not always to be trusted. Lead registered in all analyses and was definitely present; however, the highly elevated values were not used.

Jamaican volume III, p 201 gave rise to high lead and arsenic (1750 ppm) but no mercury and similar results were given for page 199.

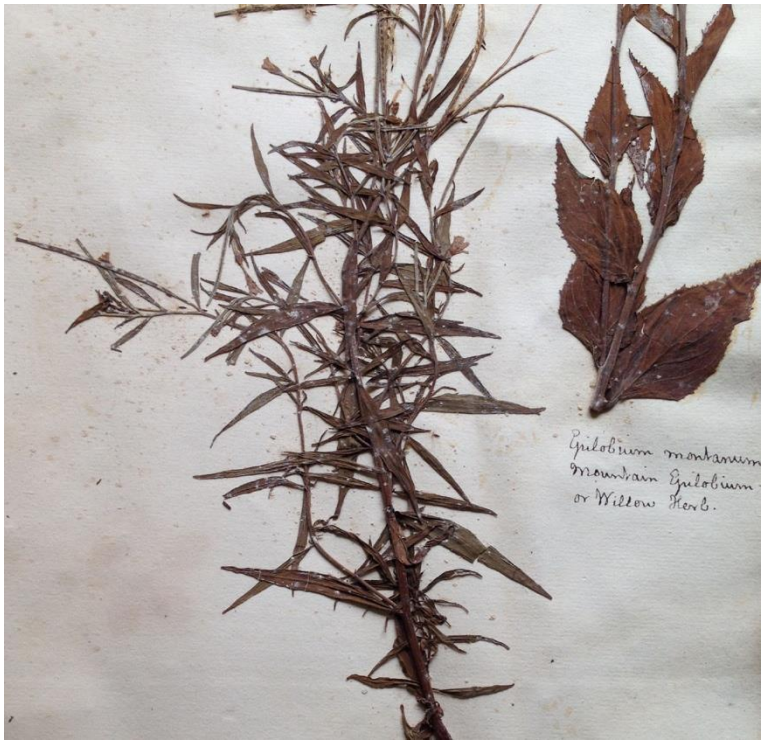

Figure 2 showing pale powder specks across paper (top left and centre) and specimen. Suspected to be Lindane a highly toxic organic biocide.

The inside cover pages of Jamaican volume IV showed a presence of mercury

(214 ppm) and lead (300 ppm). Page 345 gave just a reading of 200 ppm for arsenic. A few more pages were analysed than originally quoted because the UV scanning

did not originally detect Hg(I) and without this helpful tool, pinpointing historic treatments is much more difficult. The final outcome did confirm that high

concentrations of the toxic elements mercury, arsenic and lead and some suspected toxic organic compounds were present. This obviously impacted on the speed and ease of working with this collection.

The results of the analysis are shown in Table 1.

There are current guidelines on the level of toxic elemental vapour in air that is assumed to be safe for both environmental levels and for workplace exposures. The

short term and long-term exposure levels for the identified elements are present in Table 2. It must be stressed that these data relate to the amount in air that can be breathed in. Table 1 relates purely to the concentration found in the paper within an area of c. 33 mm^2.
Nitrile gloves are recommended for use with mixed unknown contaminants, but the herbarium volumes were extremely vulnerable to poor handling, wearing gloves reduces dexterity notably. In such circumstances use of a barrier cream such as DermaShield® is recommended. It is a foam that bonds with the skin and is effective in preventing absorption of numerous chemicals through the skin for a maximum of 5 hours. This was used whenever handling the volumes was necessary and was found to be extremely effective.

Inhalation is less easy to counteract. It is essential that there is ample ventilation or a fume hood to help remove contaminants. The volumes produced a strong, smoky odour which was not unpleasant, but persistent. Inside the books the odour was less apparent, but care had to be taken especially as the work involved incorporating moisture which can help release contaminants, especially organic biocides.

Table 1 Summary of results, all figures in ppm (µg/g).

	Results of XRF analysis on the 4 Volumes												
Volumes	B 1	B1	B1	B1	J1	J1	J1	J3	J3	J3	J3	J4	J4
Page and characteristics	P53 Grey spot	P132 Black spot	P132 Specimen	Modern paper	Outer cover	P193	P152	P201 Leaves	P199	P201 Nr stem	Leaves	Inside cover	P345
Metal measured in µg/g													
Arsenic	40	20	40	24	100	1550	1767	20	1700	1750	20	n/d	1200
Lead	130	308	447	45	790	d	d	50	d	d	50	214	d
Mercury	60	20	20	100	n/d	n/d	n/d	40	n/d	n/d	40	300	100

Key: B1 = British Volume
J1 = Jamaican volume 1
J3 = Jamaican volume 3
J4 = Jamaican volume 4
n/d = not detected
d = detected in high concentrations, no reading given

5. Results

Lead and arsenic are class A oncogens and mercuric chloride is a possible human carcinogen. Table 2 provides a summary of the symptoms and of the exposure levels not to be exceeded. When considering carcinogens, can there be a

safe level? The levels present in the volumes could pose a risk to the public if certain precautionary measures are not taken. Workplace Exposure Levels (WEL) refer to the legal requirements set to

control the extent of exposure at work. An MEL relates to the maximum exposure limit for a particular substance over a set period of time.
Currently there is no data relating to the amount of heavy metal contamination from paper that can be absorbed through

the skin or ingested for lead, mercury or arsenic via hand to mouth contamination; the only data provided by HSE is for the substance in air (mg/m^3) and therefore the potential of exposure from inhalation through contaminated air.

Previously unpublished research data from the author (Table 3) can provide extra information on the amount of mercury present on a sheet equating to the concentration of mercury vapour being released into the environment.

6. Toxicological Data

Table 2 Summary of toxic effects of common historic biocides (HSE, 2005).

	Mercuric chloride	Arsenic trioxide	Lead arsenate
Reproductive problems	Foetal damage and genetic mutations, Kidney damage	Malformations of mice/rat off-spring	Reproduction problems in men and women. Prenatal exposure can cause premature birth, low birth weight, decreased mental ability, learning difficulties, and slow growth.
STEL (mg/m^3)		-----	Presently unavailable
LTEL (mg/m^3)	0.020	0.1 WEL	0.15
Current values (mg/m^3)	0.02 WEL	0.1 MEL	0.1 Ceiling
Routes of entry into system	Absorption through skin, inhalation, ingestion	Absorption through skin, inhalation, ingestion	Ingestion, inhalation
Short term effects	Eye irritation, damage to CNS, damage to lung and irritation, coughing, possible pulmonary oedema.	Hoarse voice, irritation to nose, eyes, skin and mucous membranes, nausea, vomiting, diarrhoea, weakness, loss of appetite, coughing, chest pain, giddiness, headache, breathing difficulty.	Cough, sore throat, sore eyes and red skin, vomiting, diarrhoea and abdominal pain, oedema, conjunctivitis and liver enlargement.
Long term effects	Sore gums, shakes, memory loss, weakness, loss of teeth, poor appetite.	Heart, kidney brain, lung and gastrointestinal tract damage. Eventual skin, bone marrow and peripheral nervous system damage.	CNS damage and death
Carcinogen	Possible human carcinogen	Class A Oncogen	Class A Oncogen

Table 3 Results for total mercury emitted from a sealed environment over 48 hrs in a chamber of $0.3m^3$ at a temperature between 18-22ºC.

Herbarium Sheet	Hg on sheet (µg/g)	Total Hg emitted from sheet (µg)
A	400	0.7
B	421	0.7
C	50	<0.1

The Time weighted Average of mercury vapour deemed as acceptable during an 8hr working day (HSE, 2005) is $0.02mg/m^3$, the equivalent of 20µg/g.
As the data is currently very limited in this area, the results cannot be substantiated. The results from Table 3 do help to provide some baseline measurement from where to make very simple calculations. Therefore, if one sheet with 400µg/g of mercury and emits 0.7µg/g mercury vapour it would take exposure to approximately 30 herbarium sheets before reaching the total amount for current long term exposure limits (LTEL) currently 8hr at $0.02mg/m^3$ (20µg/g).

7. Recommendations

- Apply barrier creams such as DermaShield Plus™. This will

provide up to 5 hours of effective protection from a number of chemicals and is often preferred to wearing gloves.

- Nitrile gloves can be worn to provide effective protection from most chemicals. After use dispose of the gloves taking care not to contaminate your clean hands.
- Always wash hands after handling material and prior to eating, drinking, smoking or applying make-up.
- Work on the material in a well-ventilated room (preferably air conditioned with 10+ air changes per hour), or work on the object within a fume cabinet. Exposing the book to extraction would be advisable.
- Packing materials can include microchamber™ boards and papers. These consist of layers of activated charcoal that are very effective at removing vapours from the atmosphere and locking them into the charcoal.
- Good housekeeping will ensure that areas are kept clean and free from dust. Dust can become contaminated and provides a simple method of contamination through ingesting and breathing in air-borne dust.
- Inform all visitors and staff working on the collections that some material is contaminated and make sure they are aware of where these collections are. Ensure they are trained in the best ways to protect themselves, for example wearing of protective personal equipment (PPE) and the wearing of lab coats, but only within the contaminated areas.
- Masks can be worn but it is advisable that these are fit tested by a qualified health and safety advisor and that the correct mask is used for the specific type of contaminant.

7.1. Media Filming

The basic principles of the decision making process, through to the analysis and eventual conservation of the volumes were filmed. The filming was expected to follow a silent process of events with voice-overs added at the end. The curators later decided that a 2-way conversation would be more appropriate; however this required the purchasing of a microphone which unfortunately produced a loud hum that muted the speaking parts of the filming process. Editing was very difficult due to the amount of work to be covered and not enough takes or re-works taken at the time due to travel and time issues. The filming was undertaken over 2 1/2 days and a substantial amount of editing (~4 days) was taken to create a few useable sequences which will be uploaded onto BMAG's website.

7.2. Conservation prior to Digitisation

All four volumes were surface cleaned using a smoke sponge (Figure 3) and a plastic eraser. The British volume had a thick layer of powder on the pages which was evident when cleaning commenced (Figure 2). To prevent disturbing the powder, which was suspected to be a toxic organic compound, these pages were cleaned with extreme care.

The volumes were all in need of conservation, but volume IV was much more heavily soiled than the other volumes (Figure 4).

Figure 3 Showing the dirt picked up by the smoke sponges after a few pages of the Jamaican volumes.

Figure 4 showing the extent of surface dirt on the specimens and labels.

The majority of the books were coated with dirt (Figure 3) but the Jamaican volumes were particularly dirty. To prepare the books for the digitisation process, stabilisation of the bindings was undertaken. This involved cleaning, stabilising and re-attachment where possible. The leather was also treated with a solvent based leather feed that helped to nourish and relax the aged leather.

7.3. Digitisation and specifications

All of the four volumes were digitised and the images processed. Each image was re-named with allocated tiff files.

Images were captured using a Canon 6D DSLR and EF 24-105 mm f/4L IS USM lens with lighting provided by *Kaiser fototechnik*RB 218N HF Lighting unit consisting of two light banks each equipped with a cold light fluorescent lamp (18 watt, Colour temperature: 5400 K, CRI: 90-100), angled and adjustable in height. Individual specimens were subjected to photographic lighting for ~30 seconds. Each volume was positioned carefully prior to imaging to ensure the pages were completely flat and that there was no shadowing (Figure 5).

Images were captured in RAW format (5472x3648 pixel dimension), using the Adobe 2012 colour space. Post-processing was undertaken on the RAW.CR2 files using Adobe Camera Raw and Adobe photoshop CC. This consisted of Colour and white balance calibration using Munsell Color X-rite ColorChecker®, Lens profile correction and minimal sharpening. Along with the colour chart, a scale was included in the first capture of each digitization session to allow the addition of a scale as a separate layer to each image if required. Final processed images are saved as TIFF files with LZW compression applied.

Figure 5 Jamaican Volume 3 being supported from below to produce a flat surface.

Figure 6 Double-page spread taken from Jamaican Vol. 3.

Figure 7 Actual detail at full resolution (highlighted portion from Figure 6).

Each of the double-page spreads of the British volume had to be captured using two single images – that of the facing page with the specimen and the reverse of the previous page. This volume was the largest of the 4 volumes and took twice the amount of time to digitise, compared to the Jamaican volumes. The two images were then digitally 'stitched' at the seam to create a single double-page spread. This technique allowed the double-page spread to be viewed without losing resolution of detail. The Jamaican volumes were of a suitable size to allow for double-page spreads to be captured using one exposure.

7.4. Data Capture

All of the data images were captured and transferred for label printing. This was included as part of the process as it was a lengthy process. Each handwritten piece of information on the original specimen sheets, within each volume was digitally "cut out" and copied to a sheet of labels, which was then printed to actual size on acid free paper (Figure 8). Once printed, all of these image labels had to be physically cut out and adhered in place on the associated sheet with its corresponding specimen.

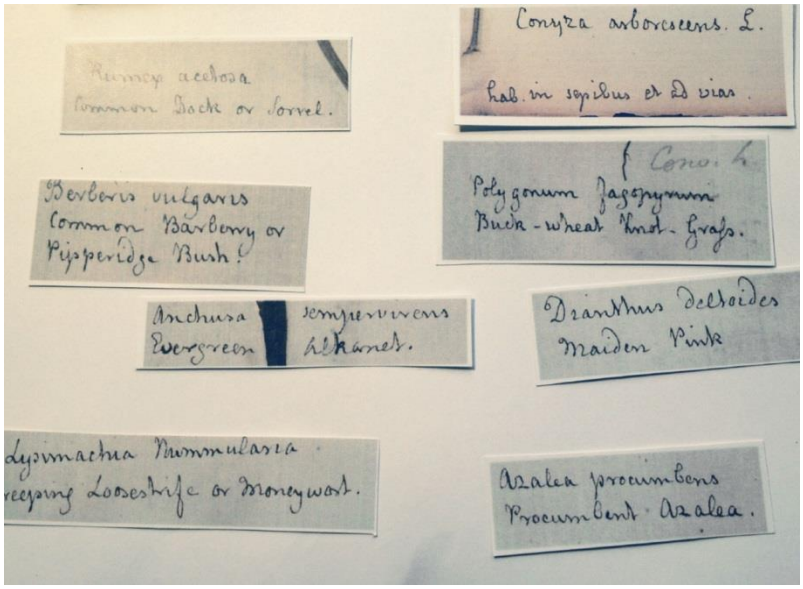

Figure 8 Examples of the captured data labels after printing and cutting out.

7.5. Removal and conservation of specimens

The aim of this process was to remove each specimen from the books and replace onto archival herbarium sheets with its corresponding imaged label. This required that each specimen be humidified using moisture and where necessary low level heat. The British volume of specimens had been adhered with a fish glue, but the Jamaican volumes had an odour of pine or camphor, probably originating from the spine glue of the volumes.

The removal process is very time consuming. Each specimen appeared intact within the book, however on close inspection it is possible to see cracks and fissures throughout the specimens due to the original drying of the glue, causing the specimen to break apart and further damage is caused when each page is turned. There was also much loose material caught in the gutter of the books. On removing the specimen, it was sometimes necessary to completely re-piece the specimen, very much like a complex jigsaw. The specimens that were broken or did not respond to the removal did take several hours to bring back together.

Some of these specimens had been glued heavily which meant that a simple 'preservation pencil' style humidification was not appropriate. It would have made the paper and specimen too wet in the time it took for the glue to soften. Instead a poultice was applied to the other side of the page. The poultice comprised of a gelatine and methyl cellulose paste, applied to a piece of bondina® (chemically inert, polyester material), placed on the back of the specimen page. The paste was then kept moist with a piece of melinex® (archival polyester sheets). This combination of both methyl cellulose and gelatine paste together worked well as they provided greater reversibility properties and worked more sympathetically with the plant tissue. It softened the glue but did not soak into the paper or the specimen. This technique prevented some of the drying out issues that were encountered previously with the bulky specimens of *Rosaceae*, *Urticaceae* and *Euphorbiaceae*.

Once the specimen had been humidified and was able to be removed, it was placed onto a new archival herbarium sheet.

The amount of glue that was present on the specimen dictated how long the conservation process would take. Large amounts of glue (Figure 9) took longer to humidify and could affect the specimen's chemistry, rendering it more brittle. Once the specimen was removed, excess glue was dabbed away from the specimen and from the original page. There were recurring issues with this glue, it leaves marks on the herbarium sheets and can cause the book leaves to stick together. This makes working quickly very difficult. If wanting to work on more than one specimen in a short period of time, you would be pressing down on a page previously worked on but the glue would remain tacky for many hours. Even when interleaving and removing the excess glue, it was a regular occurrence to go through each book, time and again to separate the leaves. Long term storage conditions should be set for 55% RH (± 5%), and a temperature of 20°C ±2°, otherwise it will be necessary to interleave each page of the volumes with a non-stick paper or similar material. Together with the specimen on the sheet, a fragment envelope was made to collect any loose material and this together with a header label and its data label was then adhered to the sheet.

The specimen was then anchored with strips of linen tape. The tape is backed with gelatine that is moistened with a damp sponge and this causes the gelatine to swell and form a strong bond between the paper substrate and the tape (Figure 10).

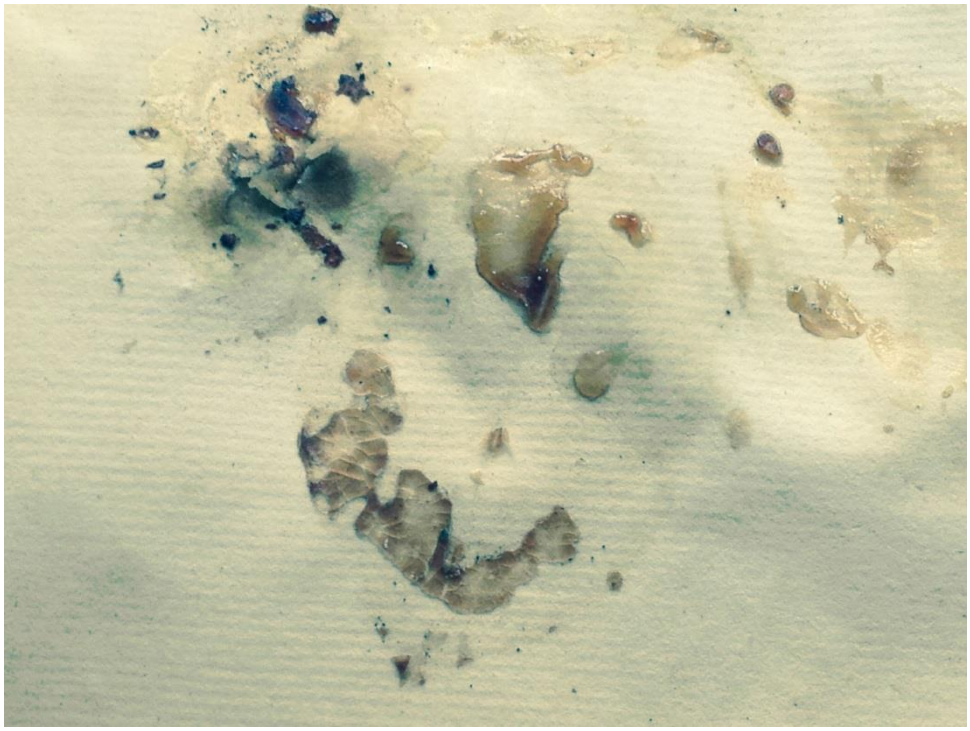

Figure 9 Remaining glue in book after specimen removal. Animal glue has been heavily applied and is showing signs of cracking. Excess glue can become tacky and re-stick adjacent pages.

Figure 10 Example of a completed specimen. Of particular relevance and scientific importance is that this is a 'type' specimen determined as *Cassia broughtonii* Fawc & Rendle. It is now renamed *Chamaecrista nictitans var. jaliscensis* (Greenm.) H.S. Irwin & Barneby – Sensitive Partridge Pea,

This method of attachment is totally reversible, however there is frequently residual glue present on the specimen and this too adheres the specimen to the paper. Some material that was broken or loose was married back to the specimen using a gelatine adhesive, a weak concentration ~ 10-15%. Larger amounts of material were captured in fragment envelopes.

7.6. Damaged or unidentified material remaining in the volumes

Some specimens within the volumes were incomplete through pest damage or from mechanical damage. These specimens were deemed too sensitive to remove from the book. It was agreed with the curators that they will use the digital images of the original volumes and print out the corresponding images to be incorporated into the collections; placed in the appropriate family folder. This process has also been agreed for some of the lower plant material that was not identified. The images can be sent to specialist institutions for either accurate identification, or just to order/family level, which would allow the specimens to be removed at a later date and incorporated into the folders. Lower plants are not usually mounted onto sheets as there is a higher risk of damage and loss from abrasion. These would ideally be placed upright in packets for ease of access. This could be carried out for the entire lower plant collection at a later date.

7.7. Systematic nomenclatural order

Once all of one volume had been mounted and labelled each specimen had to be placed into a systematic nomenclatural system. It was agreed with the curators that the specimens would be placed in family order so that when the time came the collection could be filed using a preferred system such as *Flora Europaea* or Durand, for example. This entailed finding the generic name of the specimen, or the now *accepted* generic name and then working back to find the family. Once a family name had been decided a folder was labelled with this name and the specimen was placed within. All the folders have been filed in alphabetical order. The British volume was kept separate from the Jamaican volumes.

7.8. The Leather volumes

The emptied leather volumes were given a clean with a smoke sponge. The leather was treated with a mixture of lanolin and white spirit, which is sympathetic to the sheep skin leather. The leather was much deteriorated and powdery to touch. Any movement or handling caused abrasion and flaking of the paper and the leather. The leather treatment has helped to provide a small amount of suppleness to the spine during its recent elevated levels of use, for example opening for scientific assessment, cleaning, and again for digitisation and then for conservation of the specimens. Once all work was complete, the pages were checked again to ensure all pages open easily. The leather was given a final treatment and the book board edges were strengthened with Klucel G dissolved in alcohol. This is a compound that provides strength and support to friable and weakened edges. Four custom made boxes were ordered to house the leather volumes (Figure 11). These were lined with plastazote® (an inert dense polyester foam) to ensure cushioning and to help prevent movement and slip within the box during transportation. Cotton tape was also strapped into and under the plastazote® and tied around each volume to keep the loose sections in place and to stop any further movement/loss and abrasion during transit (Figure 12).

Figure 11 Image of custom made archival box for the bound volumes.

Figure 12 Showing reinforced, archival cardboard box, with a plastazote® base and soft cotton ties to limit movement. The specimens have since been boxed and transported back to BMAG.

8. Conclusion

Removing the specimens from the volumes has decreased the amount of biocide contamination that staff and

visitors can be exposed to. The level of contaminant on the specimens themselves is always lower than the surrounding paper due to the waxy cuticle naturally encasing botanical specimens (Purewal, 2012). Removing the specimens from the pages greatly reduces the amount that can then be emitted into the environment. As the specimens are now re-mounted onto archival herbarium sheets this has also greatly negated any handling issues that could have been a major concern.

This work has highlighted the fact that the volumes have been contaminated with arsenic, lead and mercury, that the British Volume was fumigated with methyl bromide and potentially has lindane, or a similar powder applied to the pages as an acid neutraliser for the paper.

Volume 4 of the Jamaican specimens was much dirtier than the former 3 volumes and had a slightly different glue applied that was much darker in colour. This volume also gave off a distinct odour of naphthalene, an aromatic hydrocarbon that is also a suspected carcinogen.

Removal of some of the residues is possible. Laser ablation has been found by the author to successfully remove lead, however arsenic was not affected and there were no results for mercury (Purewal, 2012). Super critical carbon dioxide has also been effective at removing some heavy metal residues. Mercury was very efficiently removed but arsenic less so (Tello *et al.*, 2005a, Tello *et al.*, 2005b).

It would be of benefit to the collection if microchamber™ board were incorporated into the boxes and the cabinets as this will remove any vapours that will be emitted over time from within the boxes or from the specimens, greatly mitigating future exposure.

As can be seen (Figure 13), the majority of the specimens responded very well to removal from the bound volumes. A few specimens did not respond well to removal due to irregular thickness of the glue applied to the underside of the specimens. Often specimens were already fragmented before conservation began and some specimens suffered from the long exposure time required to moisten the often thick layers of glue during conservation. Once the glue was mobile, other areas of the specimen would have begun to dry out and in a short time this caused shrinkage and later fragmentation which is visible on some specimens. The specimens then had to be painstakingly pieced back together. This was an unanticipated, lengthy process which did contribute to an extension on the final end date of this project, but all parts of these specimens are still present for access and research.

This collection has type specimens (Figure 14) as well as other important material and many uncommon British specimens, which are all in excellent condition.

The collection is now safe to handle, is fully accessible through digital imagery and media and within a systematic order, so that ease of access is greatly improved. This collection is deemed very important to BMGA and is in surprisingly good condition. Now that the collection has been mounted and housed appropriately, it will be a valuable resource for many generations to visit. Collaborative research work has commenced with the Natural History Museum of Jamaica, Institute of Jamaica with an aim to verify scientific names and localities for the Jamaican volumes. Additionally, fieldtrips will be conducted where possible in both Jamaica and Bristol with the aim of verifying the findings or information gathered from the volumes to observe and document the changes over the centuries.

Figure 13 One of many *Epidendrum* specimens preserved within the Jamaican volumes.

Figure 14 Type specimen of *Portlandia grandiflora*

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