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

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Abstract

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

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

Introduction

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

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

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

In this era of data, where we are more equipped to share and aggregate information, there is a clear and recognized need to establish reference protocols that allow the standardized recording of

Blaschka collections. This applies as much to images as data, to allow sharing between colleagues, researchers, and museums to enable analysis, comparison, and assessment. Today, high quality digitization requires large teams, expert-level experience, expensive equipment and software, time, and space. Most museums do not have the resources to achieve this. For a standardized imaging protocol to be successfully universal and applicable to all collections, a resource efficient approach capable of producing high quality, accurate, digital surrogates of each model is required.

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

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

Materials and methods

Photography equipment and software

Quality object photography requires a camera proven to work for product photography, but final camera choice will depend on photographers'

ability level and preferences. Some of the best cameras for product photography include: Sony Cyber-Shot DSC-RX10 II; Sony A6100; Fujifilm X-S10; Sony RX100 V; Olympus OM-D E-M10 Mark IV; Nikon D3500; Canon Rebel SL3; Canon EOS M50 Mark II; Sony A7R IV; Canon PowerShot G1 X Mark III.

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

Results

Photography workflow

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

Set up

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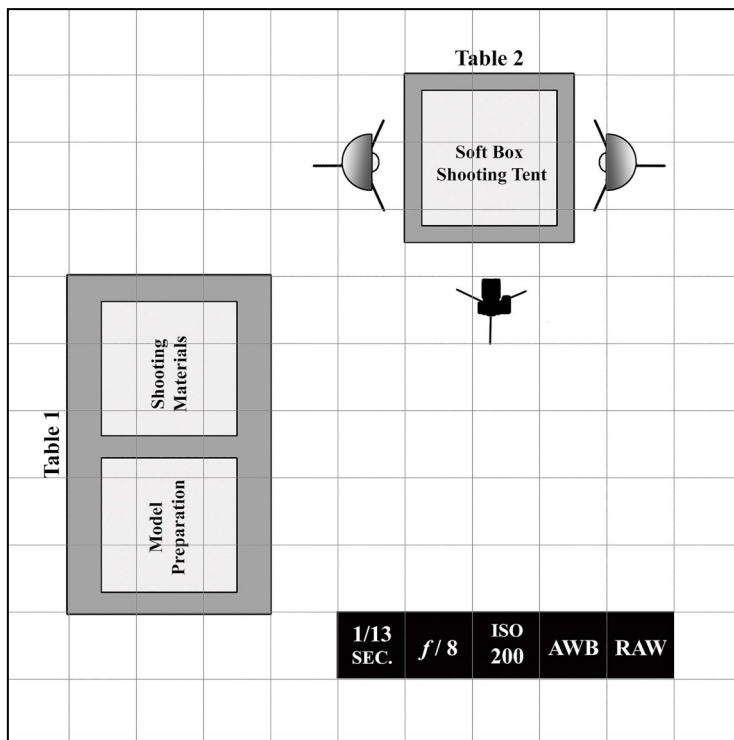

Figure 1. Baseline studio set up. Plan view.

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

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

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

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

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

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

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

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

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

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

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

Damage reference
The existing physical damage on each model is a

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

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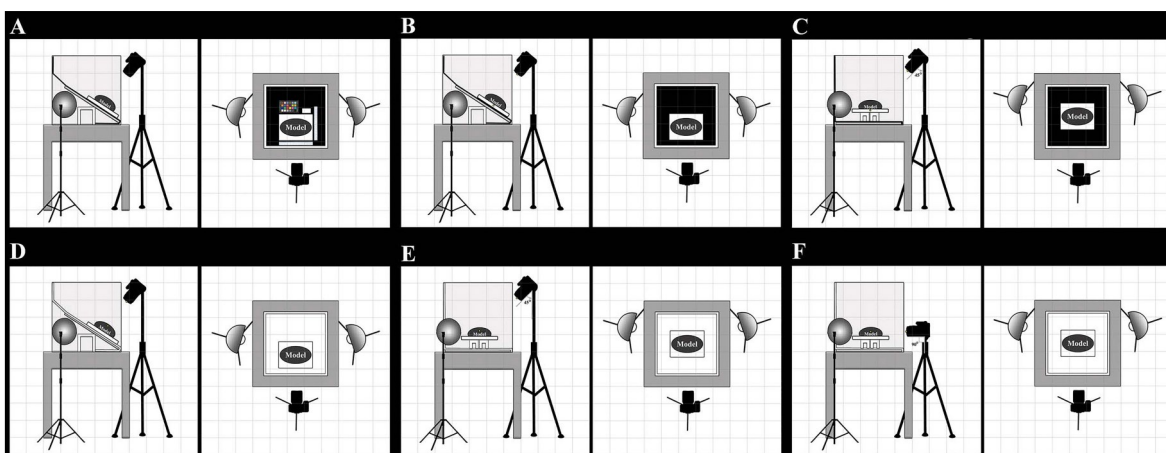

*Figure 3. Standardized shooting setup for Taxonomic Reference image Formats 1-6. Side view and plan view shown for each format. **(A)** Format 1: Reference Image **(B)** Format 2: Museum Plan View **(C)** Format 3: Museum 45° **(D)** Format 4: White Plan View **(E)** Format 5: White 45° **(F)** Format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

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

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

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

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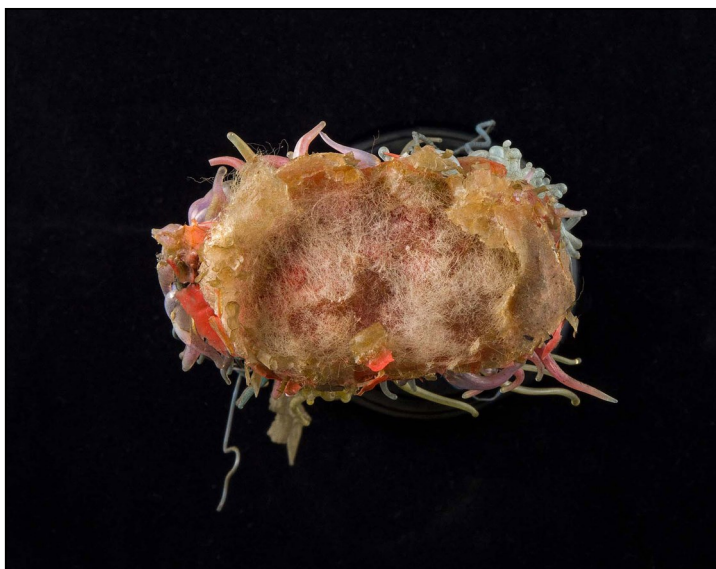

Figure 4. Detail of cotton fibres identified in Physalia caravella *[210] NMINH:2009.68.8.*

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

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

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

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

For both formats, the camera was set to black-and-white, and its contrast parameters were bumped up to +1 or +2 to maximize contrast and capture minute details (Coscia, 2012). The X-Rite target and software were not used for these formats, because the final edited images will be inverted, black-and-white images. However, the grey card was still used for exposure adjustments, and an initial snapshot with the model's information card

was still taken for organization purposes. These two shooting setups tended to cause reflections on a model's surface from the photographer and equipment. To avoid this, the photographer dressed in all black, and the tripod, if reflective or brightly coloured, was covered with a black tablecloth.

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

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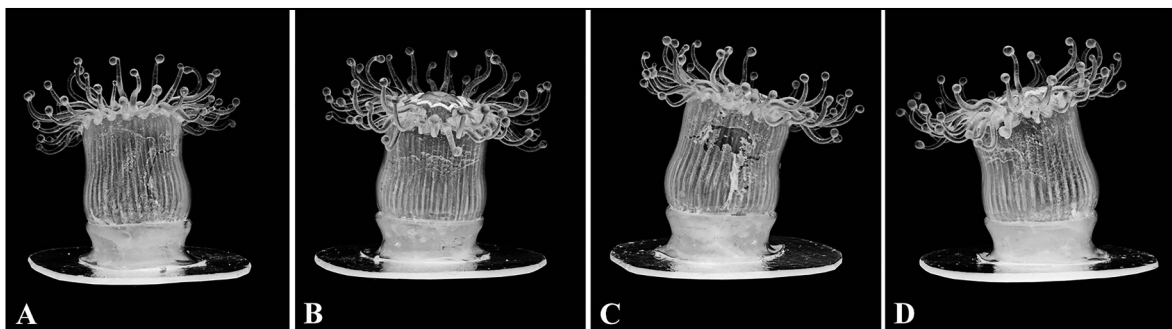

Figure 5. Caryophillia smithii [122] NMINH:1886.243.1 photographed in standardized image format 7 to highlight cracks, and structural damage.
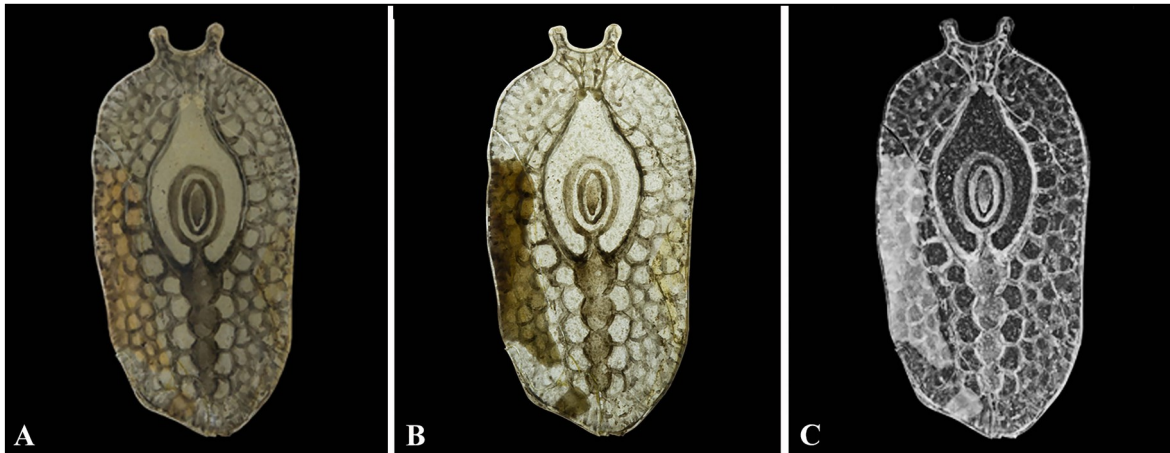
Figure 6. Stylostomum variabile [666] NMINH:1878.186.1 photographed in formats 4 and 8. Cracks extend throughout entire object. (A) Model photographed in format 4. (B) Model photographed in Format 8 before post-processing. (C) Model photographed in format 8 after post-processing.

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

Image Processing and Post-processing for Communication and Conservation

Image File Formatting

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

Creating and Applying Colour Profiles

For every image type shot in the standardized

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

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

To apply the colour profile, File 2 was dragged into Adobe Photoshop CC, prompting the Adobe Camera Raw window to open. Clicking on the "Camera Calibration" icon, the recently saved
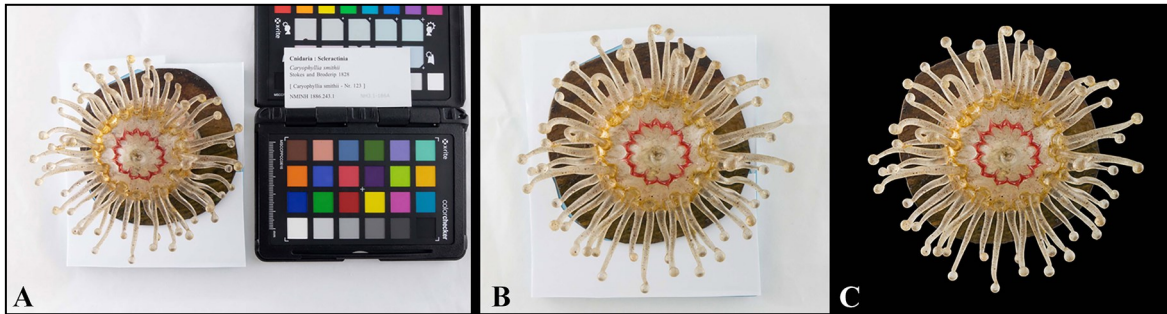
Figure 7. Colour workflow images of NMINH:1886.243.1 photographed in format 4. **(A)** *File 1 (unedited).* **(B)** *File 2 (unedited).* **(3)** *File 2 with colour profile and all post-processing applied.*

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

Applying Adjustment Layers to Images Captured in Formats 7-8

A colour profile was not created for photographs taken in the standardized image formats 7 and 8, because the final file for each image is an inverted, black-and-white image (Figure 8). Therefore, only one RAW image file was needed to create each image's final file. This RAW file included in the image frame just the model set up in a

standardized image format. For each image, the RAW image file was dragged into Adobe Photoshop CC, prompting the Adobe Camera Raw window to open. White Balance was adjusted in this window. In the bottom right corner of the Adobe Camera Raw window, the "Open Image" button was selected, opening the file in Adobe Photoshop CC. Before any further edits, this Adobe Photoshop CC file was saved as a TIFF file. The file name was created using the standardized naming formats (see Appendix I).

While this image file was shot using the black-and-white camera setting, the RAW image file still included all colour data. To eliminate colour, the "Black and White Adjustment" layer was selected and applied. Next, the "Invert Adjustment" layer was selected and applied, inverting all pixel colours and brightness values in the image. This adjustment allowed dark areas of the image to become bright and bright areas to become dark. This also emphasized subtle details originally overpowered by colour, including cracks and internal structural materials. Once these details were identified, the "Brightness/Contrast Adjustment" layer was
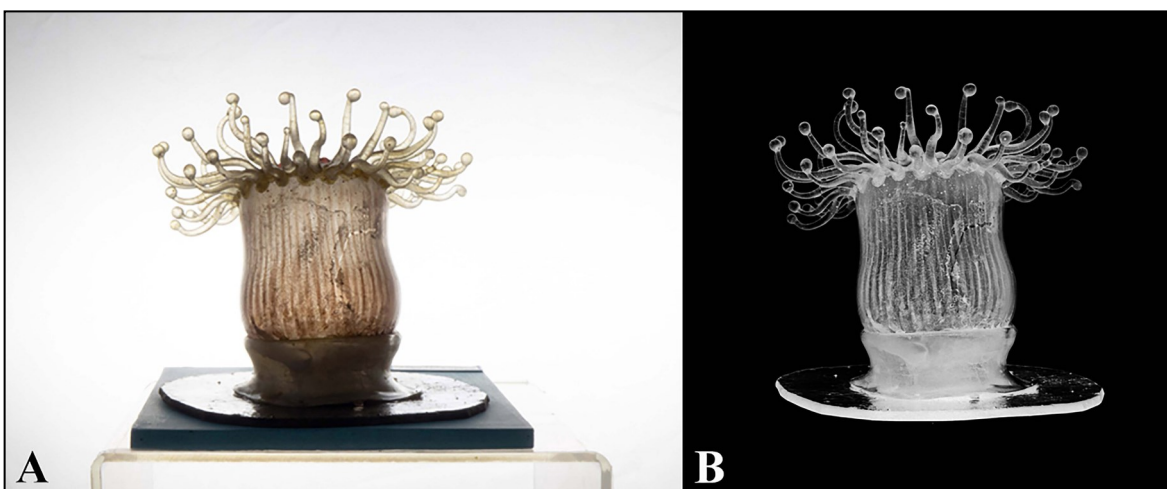
Figure 8. Caryoplillia smithii *[123] NMINH:1886.243.1 photographed in format 7. (A) Original RAW image file.* **(B)** *Original RAW image file with all adjustment layers applied.*

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

Removing Background Information

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

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

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

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

Range of Standardized Workflow Options

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

Discussion and conclusions

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

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

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

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

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

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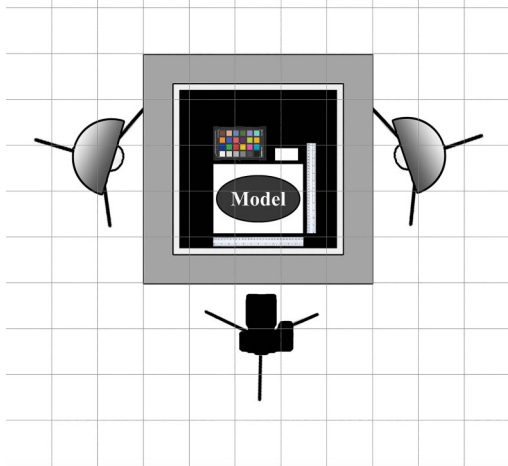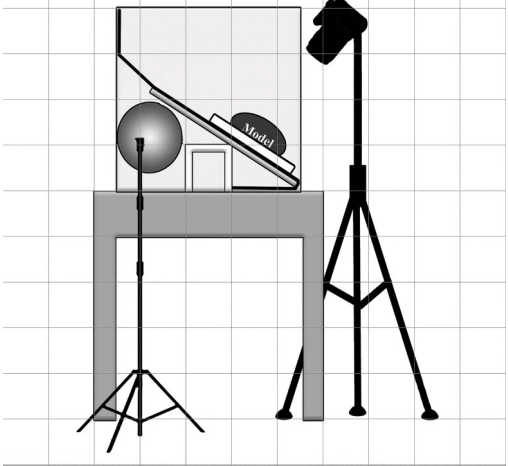URL:

Table S1 – Photography Equipment & Software

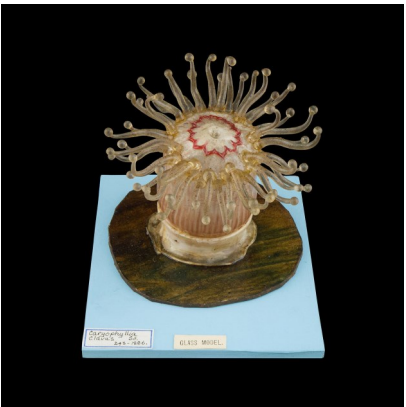| EQUIPMENT	
QUANTITY	**TYPE**
1	Sony Cyber-Shot DSC-RX10 II digital camera with attached Carl Zeiss 24-200mm f/2.8 lens (35mm eq.)
1	Studio tripod
2	7' light stands
2	10" diameter aluminium reflectors
2	135W 5500K CRI ≥ 95 Daylight Balanced CFL Photography Light Bulb
1	30" x 30" x 30" table for shooting
1	60" x 36" x 30" industrial worktable
1	24" x 24" x 24" tabletop photo studio lighting soft box shooting tent with white and black backdrops
2	Clear 1/8" thick acrylic Plexiglas plastic risers (3" x 3")
2	Clear 1/8" thick acrylic Plexiglas plastic risers (6" x 6")
1	22" x 22" x ¼" clear acrylic Plexiglas plastic sheet
-	Card stock (white and black)
1	X-ACTO knife
2	Metric rulers
6	4.5" photography spring clamps
2	Plain matte tablecloths (white and black)
3	Sandbags (5-10lb)
1	18% grey card
1	X-Rite ColourChecker Passport Photo 2 Target
SOFTWARE	
1	X-Rite ColourChecker Passport Photo 2 Camera Calibration Software
1	Adobe Camera Raw
1	Adobe Photoshop CC
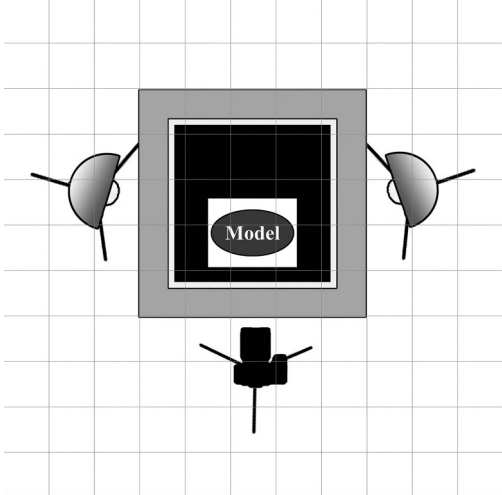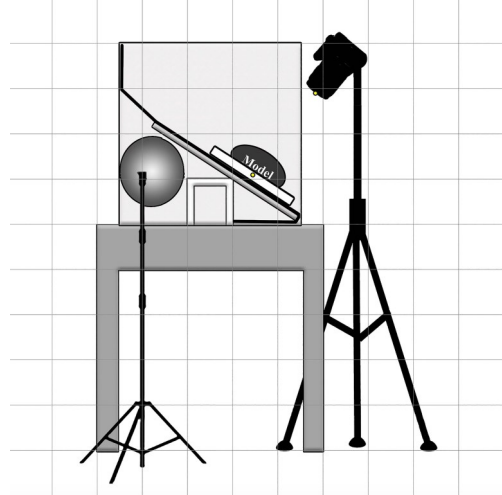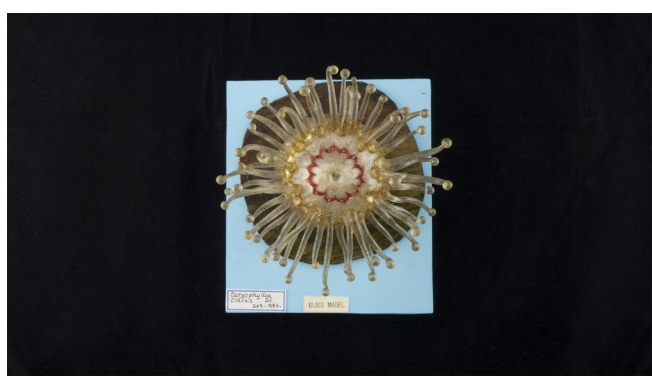
Figure S1: Setup
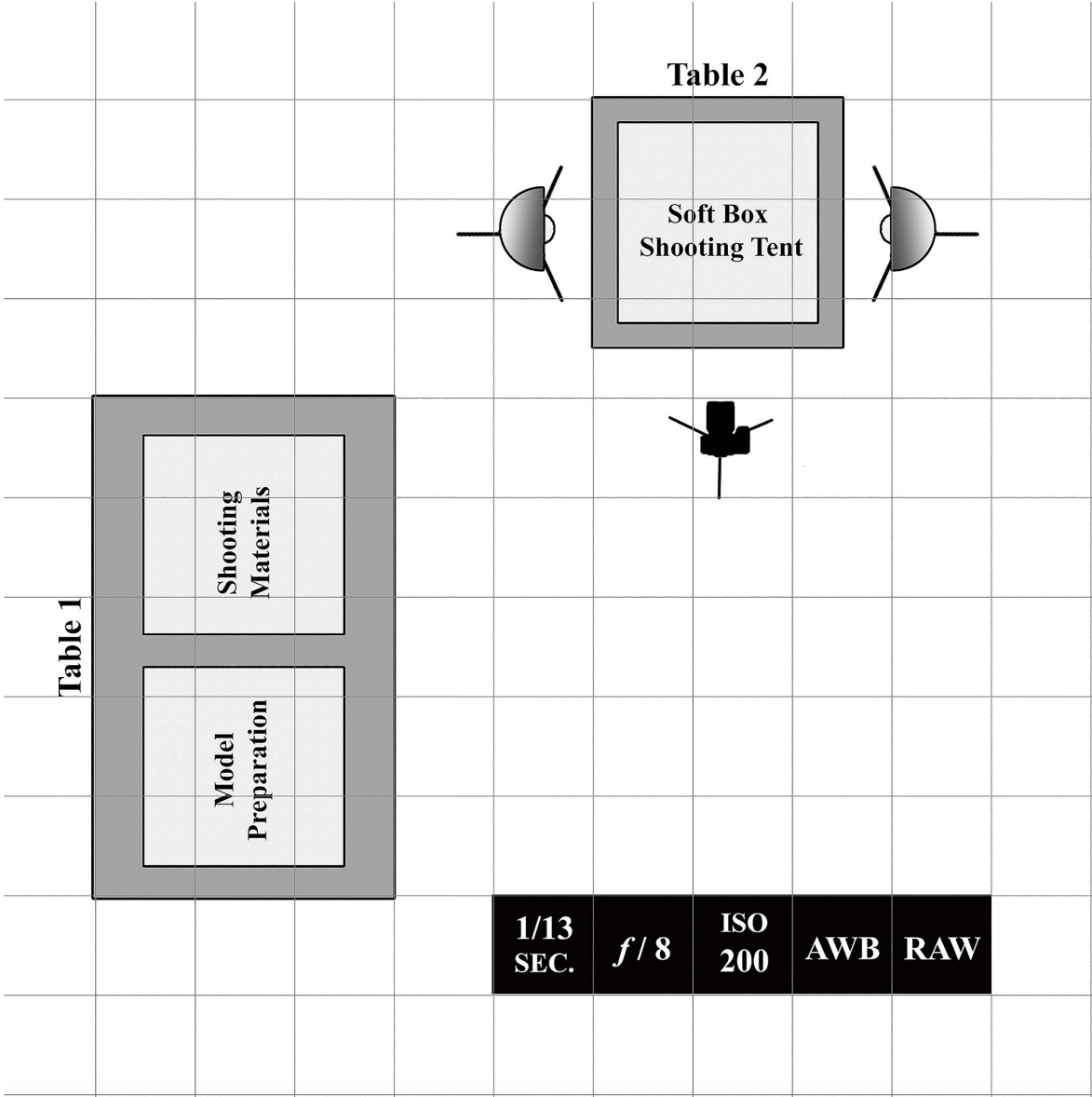
Table S2: Taxonomic Reference Image Formats 1-6

FORMAT 1: REFERENCE IMAGE
SHOOTING SETUP DIAGRAMS

Shooting Setup Description

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

Initial Format Image - Unprocessed	**Final Format Image - Processed**

Table 2: Taxonomic Reference Image Formats 1-6

FORMAT 2: MUSEUM PLAN VIEW
SHOOTING SETUP DIAGRAMS

Shooting Setup Description

A 6" riser was placed in the center of the tent. Plexiglas sheet was securely leaned against the riser, its front edge bolstered by the front of the tent. Black backdrop, used to subdue any colour cast, was secured to the tent, then draped over the Plexiglass sheet and tucked under the front of the sheet. Model was carefully placed on the bottom half of the Plexiglas sheet. If a model was larger and required more stability from the Plexiglas sheet, a second 6" riser was added next to and centered with the first riser to add support. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. Tripod was adjusted so the model could be photographed straight-on in dorsal view. Center of the camera's lens was aligned with the center of the model's base.

Initial Format Image- Unprocessed	**Final Format Image - Processed**

Table 2: Taxonomic Reference Image Formats 1-6

FORMAT 3: MUSEUM 45-DEGREES
SHOOTING SETUP DIAGRAMS

Shooting Setup Description

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

Initial Format Image- Unprocessed	**Final Format Image - Processed**
Front	

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

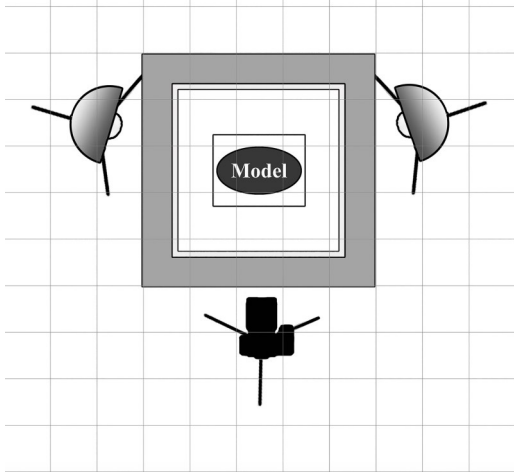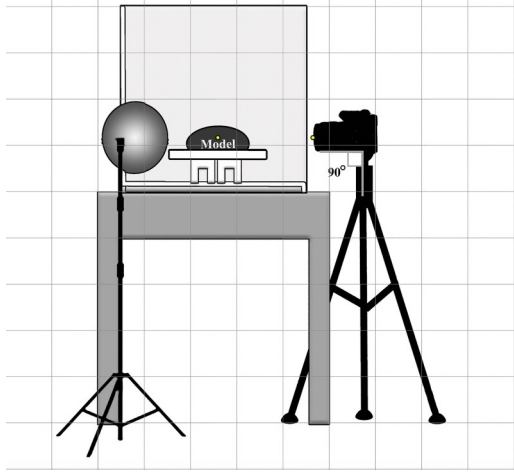| FORMAT 3: MUSEUM 45-DEGREES (Continued)	
Right	
Back	
Left	

Table 2: Taxonomic Reference Image Formats 1-6

FORMAT 4: WHITE PLAN VIEW
SHOOTING SETUP DIAGRAMS

Shooting Setup Description

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

Initial Format Image- Unprocessed	**Final Format Image - Processed**

Table 2: Taxonomic Reference Image Formats 1-6

FORMAT 5: WHITE 45-DEGREES
SHOOTING SET UP DIAGRAMS

Shooting Setup Description

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

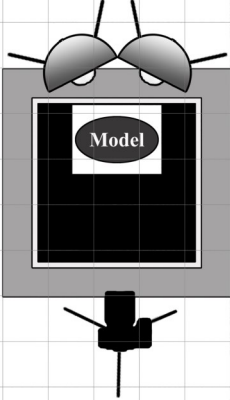| Initial Format Image- Unprocessed	Final Format Image - Processed
Front	

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

FORMAT 5: WHITE 45-DEGREES (Continued)	
Right	
Back	
Left	
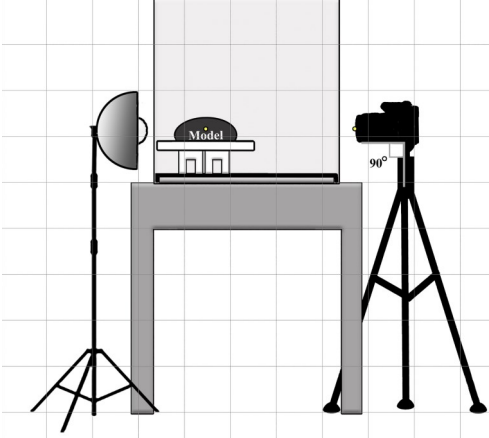
Table 2: Taxonomic Reference Image Formats 1-6

FORMAT 6: WHITE 90-DEGREES
SHOOTING SETUP DIAGRAMS

Shooting Setup Description

Plexiglas sheet was set flat on the bottom of the tent. White backdrop was secured to the tent, then draped over the Plexiglas sheet. A 3" riser was placed in the center of the Plexiglas sheet. Model, its base still covered in white card stock, was carefully positioned on the riser, with the front side facing the camera first. If a model was larger and required more stability from the riser, a second 3" riser was added next to and centered with the first riser to add support. Heights of both lights were adjusted to line up with the center of the model. Both light stands were repositioned slightly behind the model, illuminating the object without surface reflections. The camera was fixed on the tripod at 90-degrees and the center of the lens was aligned with the center of the model.

Initial Format Image- Unprocessed	Final Format Image - Processed
Front	

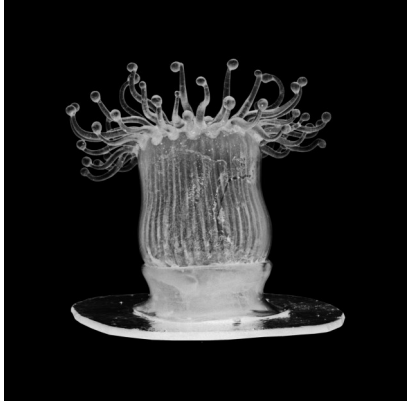**Table 2: Taxonomic Reference Image Formats 1-6 (Format 6 continued)**

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

Table S3: Damage Reference Image Formats 7-8
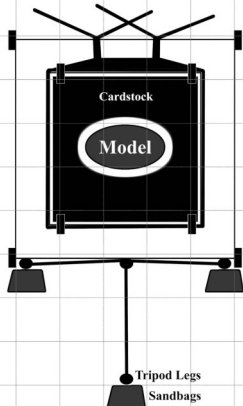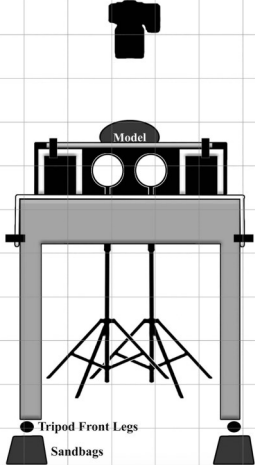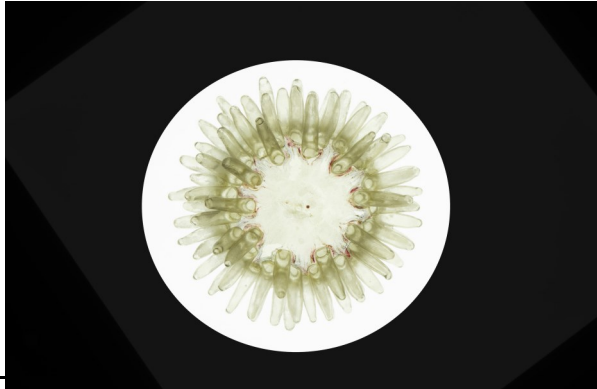
FORMAT 7: BACKLIT 90-DEGREES
SHOOTING SETUP DIAGRAMS

Shooting Setup Description

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

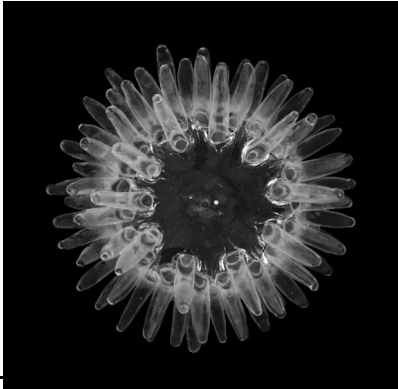| Initial Format Image- Unprocessed	Final Format Image - Processed
Front	

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

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

Table S3: Damage Reference Image Formats 7-8

FORMAT 8: UNDERLIT PLAN VIEW
SHOOTING SETUP DIAGRAMS

Shooting Setup Description

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

Initial Format Image- Unprocessed	Final Format Image - Processed

Table S4 – Range of Standardized Workflow Options

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

Image File Formatting

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

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

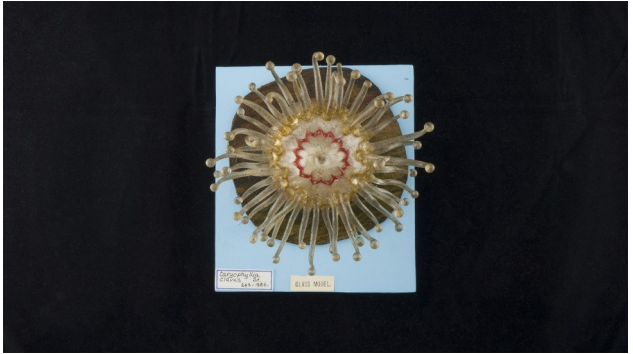**Image Processing and Post Processing for Communication and Conservation**

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

Image Processing and Post Processing for Communication and Conservation

TIMES FOR POST PROCESSING PER IMAGE TYPE	
IMAGE TYPE	**1 MODEL** (minutes)
Reference Image	5
Museum Plan View	10
Museum 45° - Front	30
Museum 45° - Back	30
Museum 45° - Right	30
Museum 45° - Left	30
White Plan View	40
White 45° - Front	40
White 45° - Back	40
White 45° - Right	40
White 45° - Left	40
White 90° - Front	40
White 90° - Back	40
White 90° - Right	40
White 90° - Left	40
Back-Lit Plan View	40
Back-Lit 90° - Front	40
Back-Lit 90° - Back	40
Back-Lit 90° - Right	40
Back-Lit 90° - Left	40
White Out Museum Board	40
TOTAL	**735**

*Time is completely dependent on the type of model being processed. These times are averages of recorded processing times from multiple model types. These times were recorded by a professional editor who completed the post processing steps on a MacBook Pro (Operating System: macOS Big Sur Version 11.6. Processor: 2.4 GHz 8-Core Intel Core i9).

Other possible ways to show process on the following pages

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

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

TAXONOMIC REFERENCE. IMAGE FORMAT 2: MUSEUM PLAN VIEW – FULL PROCESS (CONTINUED)		
POST PROCESSING	Background information removed.	
	High Pass Filter Layer applied.	
FINAL IMAGE FILE		