# TECHNIQUES

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# A Workflow and Tips for Creating 3D Models of Amphibians and Reptiles using Photogrammetry

Over the past decade, there has been a dramatic increase in the availability of consumer-grade hardware and software for three-dimensional (3D) object creation (Sargent and Schwartz 2019), reducing barriers for this technology to become widely used for education and research in the biological sciences. Digital 3D models can serve as educational tools for species identification training and can increase the value of museum specimens for research by providing remote access to view specimen characteristics, such as for morphometric studies (Falkingham et al. 2018; Irschick et al. 2020a; Medina et al. 2020). Physical models are commonly used for herpetological research, such as for predation and thermoregulatory studies (e.g., Bartelt and Peterson 2005; Tracy et al. 2007; Farallo and Forstner 2012), and 3D modeling technology offers the potential to enhance visual realism and decrease time requirements for creation of physical models for research (e.g., Amado et al. 2019; Tetzlaff et al. 2020).

Despite the ease of access to hardware and software, there is a substantial amount of learning and, in the absence of a teacher or guide, trial-and-error, required to create digital and physical 3D models. The process has several important steps, and each step has a learning curve. The purpose of this paper is to reduce the learning curve for herpetologists that are new to 3D model creation by providing a full workflow, as well as tips to maximize quality of the models. The photography portion of the workflow uses a single-camera system, and thus is suitable for amphibians and reptiles that are either anesthetized or euthanized (e.g., museum specimens) prior to photographing. Irschick et al. (2020a, b) provided guidance for developing a more advanced multicamera system to enable 3D photography of non-anesthetized herpetofauna.

## Workflow and Tips

*Animal Preparation.*—If using live animals, in most cases the animals will need to be anesthetized prior to photographing in order to prevent them from moving during the 360° photography (hereafter photo) session. Animal movement during the session will cause image alignment problems and depending on the extent of movement could make the image set unusable for creation of realistic 3D models, regardless of the quality of the individual images. I have had some success with creating and then combining multiple 3D model "chunks" when non-anesthetized animals have moved slightly in the middle of the session, but this requires additional processing time, and the quality of the resulting model may be negatively impacted.

I place the animal in the center of an elevated object; I have found that a white painting canvas works well. I have several canvases of different sizes and match the size of the canvas to the size of the animal being photographed. I place small stickers on the canvas to assist with automated image alignment (Fig. 1), with the stickers scattered around the edges of the canvas. Next, I place the canvas on a flat black surface to maximize contrast for later subject extraction, where the subject will be the canvas with the animal on top. It is possible to place animals on an entirely flat uniform-colored surface, and then to extract just the animal during image processing. However, I have found this approach can require more manual image editing, as well as create problems for automated image alignment.

*Photography.*—While almost any modern day camera will be sufficient for 3D photography of amphibians and reptiles, in my opinion the ideal consumer-grade camera is a mirrorless interchangeable-lens camera (e.g., Fujifilm X series, Nikon Z series, Sony α series). Most point-and-shoot cameras have acceptable image resolution, but they can be more restrictive for framing the subjective and often lack remote trigger capabilities. The advantage of mirrorless cameras over digital single-lens reflex (DSLR) cameras is the presence of an electronic viewfinder, which allows for a constant depiction through the rear viewfinder of the subject's placement in the frame and what the final image will look like. I also recommend using a remote trigger to increase the speed of the photo session and reduce potential for blur from camera shake. Alternately, most cameras have an interval timer feature that can be used to automatically take photographs at specified time intervals.

I have found a midrange zoom lens to be suitable for 3D photography of amphibians and reptiles, around 18–55 mm for APC-S and micro four-thirds cameras. For this purpose, midrange zoom lenses are sufficient even for small species such as most plethodontid salamanders, although note that for small species it is difficult to obtain fine 3D model resolution in the

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Fig. 1. Example three-dimensional (3D) amphibian and reptile photography station. The station includes: 1) an elevated black photography platform placed on an Artograph Lightpad Revolution platform to allow the photography platform to be rotated while the camera is stationary; 2) a white canvas placed on top of the black photography platform to provide strong color contrast for subject extraction, and small stickers placed around the edges of the canvas to assist with automated image alignment; 3) two SANSI 40-watt LED daylight bulbs placed in swinging arm desk lamps for front lighting; 4) two ALZO 100 20-watt LED daylight panels for backlighting (panels placed on a small table to increase their height); 5) Fujifilm XT-2 mirrorless camera placed on a tripod with a ball-head to allow for manipulation of the camera angle.

feet. Unlike prime lenses (i.e., lenses with a fixed focal length), zoom lenses allow for changing the field of view without moving the camera itself. This is useful when the subject size varies, in this case, the canvas size. While I am not advocating for specific gear, my current Fujifilm camera setup has worked well for me, and includes an X-T2 camera, a RR-100 wired remote trigger, and a 18–55 mm zoom lens (note this is an APC-S camera). For very small subjects, using a macro lens may be optimal for maximizing detail, but note the entirety of the animal should be in focus in every shot, as each image contributes to the 3D model polygon mesh and texture.

I highly recommend rotating the subject rather than rotating the camera around the subject. It is easier, faster, allows for greater control of standardized incremental positioning, and keeps the camera distance from the subject consistent. If rotating the subject, a manual or electric rotating platform is required. If using a manual platform, ensure the platform can spin with minimal force. I have found the Artograph Lightpad Revolution works well as a manual spinning platform. I place an additional platform on top of the spinning platform so that the canvas is located around chest level, and then place the camera on a tripod at around eye-level. I recommend using a ball-head on the tripod that can swivel freely from side-to-side to allow for minor horizontal position changes as the subject is rotated. Alternately, the camera position can remain fixed and the focus points can be moved as the subject is rotated to keep the animal in focus (if needed), but this takes more time.

To maximize resolution of the subject in the image, I choose a field of view where the edges of the canvas are near the edges of the frame, while ensuring that the canvas does not go outside the edges of the frame as it is rotated (considering that I can horizontally adjust the camera during the photo session). To maximize the depth of field (i.e., the amount of the image in clear focus), I use the smallest possible aperture, which is the largest f-stop (usually f/22 for consumer-grade midrange zoom lenses). I photograph in an extremely well-lit environment to allow for adequate lighting of the subject while maintaining a small aperture, low ISO, and fast shutter speed. I currently use two SANSI 40-watt LED daylight bulbs (5500 lumen output) for front lighting, and two ALZO 100 20-watt LED daylight panels (1800 lumen output) for rear lighting. I use swing arm desk lamps with the SANSI bulbs to allow for manipulation of the height and angle of the front light sources (Fig. 1). The height and angle of the ALZO panels can also be manipulated.

For a high-quality 3D model of amphibians and reptiles, I recommend taking 35–60 images per subject, or around 6–10° rotation per image. The more angles that are captured, the better the model, and taking at least 35 images minimizes the likelihood of having image alignment problems. Having more images than are needed also allows for discarding of any blurry images without negatively impacting the quality of the model. There is no need to take RAW images, JPEG images work well. Using the setup and protocol I have outlined here, I can complete an approximately 50-photo session in 3–4 minutes.

*Image Processing.*—The goal of the image processing step is to extract the subject from the background, in this case the canvas with the markers and animal on top, without having to spend hours manually editing out the background of each image. I use Adobe Photoshop with a batch process workflow to automatically extract subjects (a feature that was introduced to the program in 2018), which takes ca. 5 min for 50 photos on my laptop computer (32 GB RAM, Intel Core i9 processor). To accomplish this (using versions 20–22), I use an action set that performs the following actions in order: 1) create a new layer from background (Color: None, Mode: Normal, Opacity: 100%); 2) select the subject (Select, Subject); 3) select the inverse of the subject (Select, Inverse); 4) delete the background (press Delete); 5) save the image (Save As, Type: PNG, Folder: Name). I save the extracted subject images to a different folder than the original folder and retain the original image name for the edited photo to keep the images in order. Once the action set is created, it is available for use in perpetuity (or until the commands in future versions of Photoshop are changed). To process a batch of photos, open Photoshop and select File, hover to Automate, and select Batch; within Batch, select the action set, choose the folder containing the original images, choose the folder where the extracted subject photos will be deposited, and click OK.

Following automated subject extraction, I view each image and perform any manual cleanup edits that are needed. This process can be as quick as a few minutes (no edits needed), or as long as several hours, depending on how well the automated image extraction performed across the photo set. Often some of the images will contain a portion of the background extracted as the subject. This is easy to fix manually using the quick selection or lasso tool. A more time-intensive issue is when portions of the animal are removed with the background. In these cases, I either remove the photo from the set, or if there is a cluster of photos with this issue, I go back to the original photos and manually extract the subject. The key to good performance for automated subject extraction is to maximize the contrast between the subject and the background. A light- colored canvas on a dark background provides good contrast, but if the camera angle is close to being horizontally aligned with the animal, for some images the head and back of the animal will be contrasted against a black (empty space) background rather than the canvas

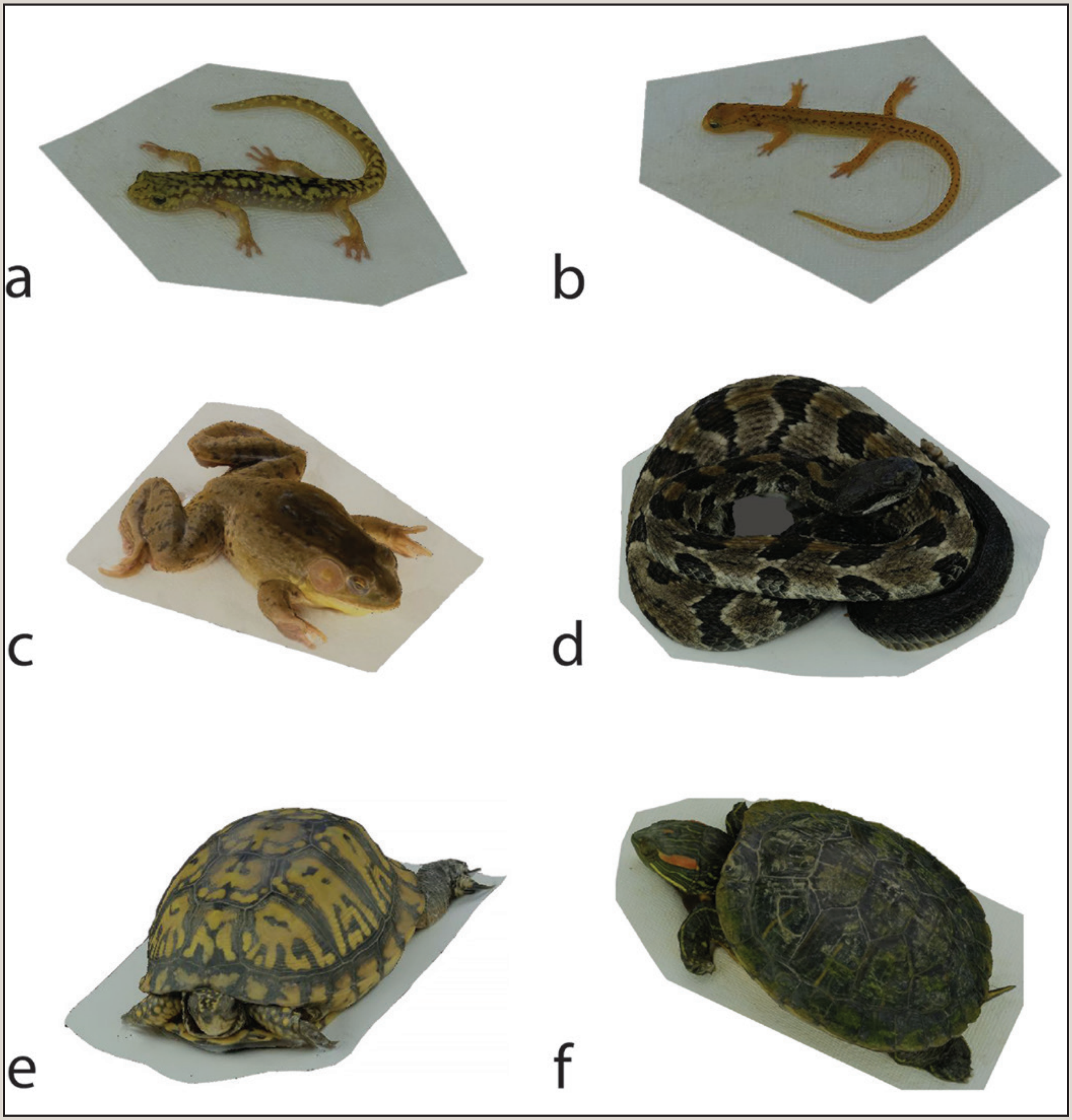


Fig. 2. Examples of digital three-dimensional (3D) models created using the workflow described in this paper: a) Green Salamander (*Aneides aeneus*); b) Long-tailed Salamander (*Eurycea longicauda*); c) Green Frog (*Lithobates clamitans*); d) Timber Rattlesnake (*Crotalus horridus*); e) Eastern Box Turtle (*Terrapene carolina*); f) Red-eared Slider (*Trachemys scripta elegans*).

or platform, and the program can have difficulty determining the subject boundary. When possible, my recommendation is to attempt to make the camera angle high enough so that the canvas or platform is visible behind the animal on all sides and at all angles. However, the camera angle should be low enough that the side profile of the animal is clearly visible.

*Digital Model Creation*.—There are many software programs available for creating 3D models using photogrammetry, including some free programs. I have tried a handful of the free programs and have found most of them to be difficult to use. I currently use Agisoft Metashape Standard Edition to create the models, which is user friendly and relatively inexpensive ($179 for a perpetual license as of June 2021). Using Metashape, I have found the following workflow usually results in successful photo alignment: 1) add photos (Workflow – Add Photos); 2) align photos (Workflow – Align Photos; Accuracy: High, Reference preselection: Sequential); 3) create mesh (Workflow – Build Mesh; Source data: Depth maps, Quality: High, Face count: High; Interpolation: Enabled; Calculate vertex colors: checked); 4) create texture (Workflow – Build Texture; Texture Type: Diffuse

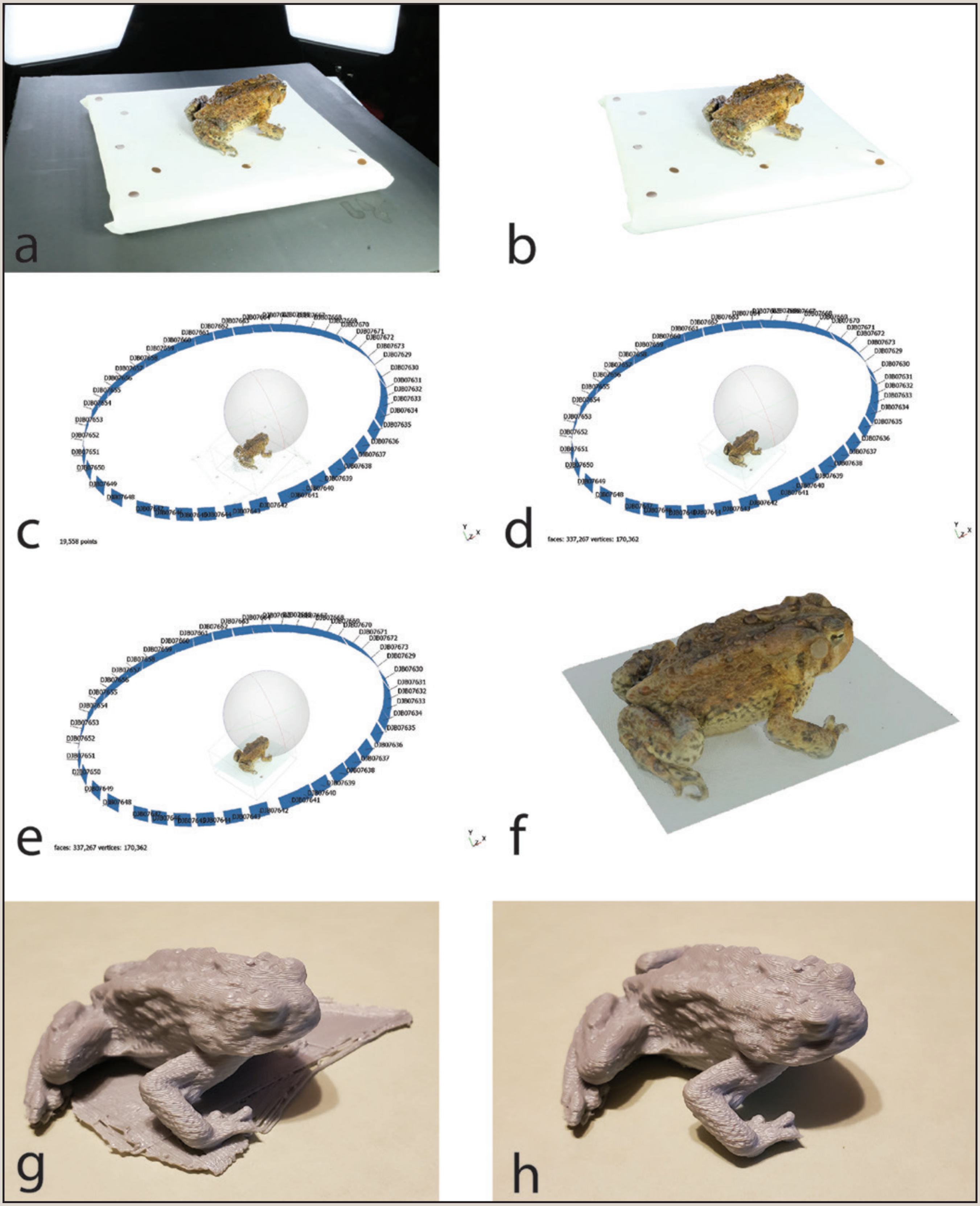


Fig. 3. Visual depiction of a workflow for creating three-dimensional (3D) models of amphibians and reptiles, using an American Toad (*Anaxyrus americanus*) as an example: a) one of 45 images taken as the canvas was rotated 360°; b) subject extracted from the background using Adobe Photoshop; c) auto-alignment of photographs and generation of the point cloud using Agisoft Metashape; d) auto-mesh generation using Agisoft Metashape; e) auto-texture generation using Agisoft Metashape; f) final digital model after manual canvas cropping using Autodesk Meshmixer; g) printed model with the canvas attached; h) final printed model with the canvas peeled off.

map, Source data: Images, Mapping mode: generic, Blending mode: Average; Enable hole filling: Checked). For texture, the blending mode is particularly influential for how the final model will appear. Average blending uses a weighted average of the individual photos, which minimizes the influence of lighting (such as shadows) in individual photos on the final coloration of the object. However, occasionally other blending options produce better-looking results. Once the model is created, I save the Metashape file (.psx) as well as export the object as a Wavefront object file (.obj), which can be used in most other 3D software programs and printers. The time required to create models in Metashape using this workflow will vary depending on the number of images, animal complexity, and computer processing power. It typically takes 0.5–1 h to complete all processing steps on my laptop computer when the quality of the mesh is set to "high."

Prior to printing, the 3D object needs to be resized, and the canvas needs to be cropped. For the canvas, it is important to crop the edges so that it becomes only a thin layer underneath the animal, which easily peels off once printed. I use the freeware program Autodesk Meshmixer and the following workflow to resize and crop the models: 1) open Wavefront object file; 2) resize object using the canvas dimensions (Edit – Transform; Coordinate Space: World Frame, Size X or Y: Resize); 3) crop object (Edit – Plane Cut; Cut Type: Cut [Discard Half], Fill Type: No Fill). This program also allows edits to be performed on the final digital model if needed. Examples of digital 3D amphibian and reptile models produced using this workflow are shown in Fig. 2. For use in research and species identification training, the digital models can be rotated to view the object from any angle.

*Printing.*—If the final model will be printed, and the object is larger than the printer bed, additional plane cuts can be performed using Meshmixer and each slice can be printed separately (Edit – Plane Cut; Cut Type: Slice [Keep Both], Fill Type: No Fill). For polylactic acid (PLA) filament, I have found that SCIGRIP 16 acrylic plastic cement works well as a bonding agent. Unfortunately, as far as I am aware, consumer-grade 3D printers capable of printing realistic full color models are not yet available. Thus, manual coloration is still necessary if the models need to look realistic. A visual depiction of the full workflow is provided in Figure 3.

## Additional Resources

Recent papers by Irschick et al. (2020a, b) contain useful information to assist herpetologists with creation of digital 3D models using photogrammetry. Both papers focus on explaining the design of multicamera systems for 3D photography, compare morphometric accuracy of the resulting 3D models to the real animals, and contain useful photography tips. Additional background information and tips for the photogrammetry process are provided in Bot and Irschick (2019). Another useful single-camera workflow paper that focused on bird museum specimens was published by Medina et al. (2020). The overall workflow is similar to what I have presented here, but Medina et al. (2020) use different equipment and software programs, and I encourage readers to consult their paper for additional guidance and tips.

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