

# Conquering the crush: A novel tool for holding crocodilian jaws open

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## Abstract

Crocodilians have diverse snout shapes ranging from the long, narrow snouts of the Indian gharial (*Gavialis gangeticus*) to the broad snout of the American alligator (*Alligator mississippiensis*). In addition, crocodilians possess the strongest bite force of all extant animals, with recorded values for adult alligators exceeding 9 kilonewtons (kN). Jaw-closing pressure poses a challenge and safety risk for people working with crocodilians, such as veterinarians, wildlife managers, and researchers who must safely access the oral cavity to perform veterinary procedures, health assessments, hook removals, or sample collection. Conventionally, polyvinyl chloride (PVC) or metal tubes (pipes) placed longitudinally into the mouth have been used to hold crocodilian jaws open for such operations. The short sections of opaque pipe can cause oral irritation, obscure the palate and tongue, and restrict access to the oral cavity and palatal valve. In conjunction with a project investigating the diet of alligators in the southeastern United States, we identified a need to create an efficient tool to allow safe and direct access to the alligator oral cavity. We built 2 versions of a device for holding alligator jaws open that are adjustable to accommodate different gape sizes. The device allows for safe positioning within the mouth, includes safety considerations for device failure, and is adaptable to both widen and collapse the gape of the mouth. We successfully deployed and

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recovered the device on 76 wild alligators ranging in total length from 120 to 329 cm. We also performed mechanical tests in the laboratory to assess the maximum force the devices and associated materials can safely withstand, as well as the conditions under which the devices fail. Our medium-duty and heavy-duty device designs withstood forces up to 6 kN and 18 kN, respectively. We observed no material fracture in the devices but did observe deformations of materials used during laboratory testing. The device is an inexpensive and effective tool for veterinarians, wildlife researchers, and managers who need to hold open the jaws of crocodylians safely.

#### KEYWORDS

*Alligator mississippiensis*, American alligator, bite force, crocodylian, gastric lavage, oral cavity, restraint

Working with wildlife comes with varying degrees of inherent risk, which can include potential physical harm to both animals and professionals during capture and handling procedures (Palmer 2009). As such, research and management of wildlife requires a diverse arsenal of tools and equipment to facilitate data collection, to catch and restrain wildlife safely, and for veterinary procedures (Kock et al. 1987, Franklin et al. 2009, Riley and Barron 2016).

Crocodylians are robust amphibious predators that are routinely captured and handled for scientific research, conservation, and management. One of the predominant considerations during the capture and handling of crocodylians is how to work safely around an individual's jaws and snout. Though crocodylians have diverse snout shapes, all possess 60–110 conical teeth and exhibit reported molariform bite forces that range from 0.67 to 16.41 kilonewtons (kN) (Erickson et al. 2012), collectively representing the greatest in the animal kingdom (in comparison, canine molar bite forces range between 0.86 and 0.91 kN; Brassard et al. 2020). During crocodylian capture and handling, biologists typically restrain the snout by taping or tying the mouth closed (Woodward et al. 2019, Boucher et al. 2020). In some cases, researchers and veterinarians must keep crocodylian snouts open for specific procedures such as inspection of the oral cavity (Perez-Marron et al. 2022), removal of foreign objects (Platt et al. 2016), stomach flushing (Rice et al. 2005, Platt et al. 2006, 2013), and endoscopy (Lafortune et al. 2005), among others. As such, tools for holding the jaws of crocodylians securely open are critical for the safety of those performing each task.

Conventionally, wildlife researchers, veterinarians, and managers have used fixed-diameter, longitudinally-inserted polyvinyl chloride (PVC) or metal tubes to hold open the jaws of crocodylians (Rice et al. 2005, Saalfeld et al. 2011, Nifong et al. 2012). However, tube placement is towards the palatine bones and may produce some discomfort in the animals. In addition, due to the opacity of most PVC tubes, some areas of the animal's oral cavity may be obscured and cannot be adequately inspected, and the space occupied by the tube limits maneuverability within the mouth and access to the palatal valve, pharyngeal cavity, and esophagus. Moreover, longer tubes with large surface areas have greater potential to come in contact with and damage teeth. To address some of these limitations, in 2021 the Staff of the Herpetology Department of The Dallas World Aquarium (DWA) created a tool to hold open the jaws of crocodylians for dental surgeries. The design was a device consisting of 2 clear acrylic bars (vertical supports) with holes drilled at each end for carriage bolts to be passed through horizontally (horizontal cross-members). The bars were wide enough that the bolts were situated wider than the snout behind the premaxillary bones. A plastic tube covers the bolts in between the upper and lower acrylic bars to keep them

separated and protects the tissue around the teeth where the bars contact the mouth. The DWA team used this device (hereafter, the acrylic jaw prop) during 2 medical procedures: a) examining the oral cavity and removing debris from multiple periodontitis caused by chronic osteomyelitis in an adult female Morelet's crocodile (*Crocodylus moreletii*) and b) removing a periodontal fibroma involving teeth in an adult male American alligator (*Alligator mississippiensis*; Figure 1). In both cases, the device proved to be easy to assemble, and the placement was strong enough to keep the jaws open, allowing clearance and free movement of tools inside the mouth.



**FIGURE 1** (A) Deployment of the acrylic jaw prop to keep crocodilian jaws open on an American alligator (*Alligator mississippiensis*) with a periodontal fibroma, and (B) a Morelet's crocodile (*Crocodylus moreletii*) with chronic osteomyelitis and multiple periodontitis. (C) Lateral (left) and rostral (right) view of the acrylic snout opener in the skull of an alligator with the device cross-members placed on the premaxillary teeth. Photos by L. Sigler (The Dallas World Aquarium).

Concurrent with the work by DWA, our field research team identified the need for a plastic free crocodylian jaw prop for use on wild alligators to facilitate the collection of stomach contents for ongoing diet and ecotoxicology research. In collaboration with the DWA team, we adapted the design for the acrylic jaw prop to create a device that is not made of plastic (metal) and easily adjustable to accommodate different gape sizes. The metal jaw prop device allows for safe positioning within the mouth, includes safety considerations for device failure, and is adaptable to both widen and collapse the gape of the mouth. Here, we present the design as well as results from field deployments and mechanical testing of the metal jaw prop device.

## STUDY AREA

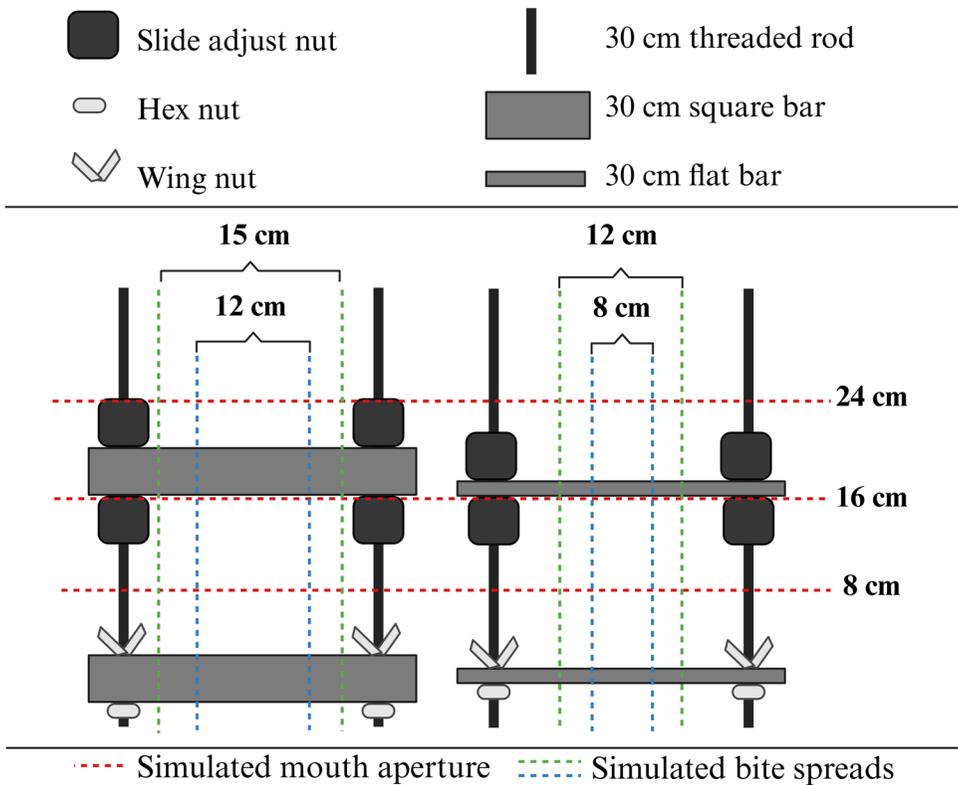
We conducted device testing at the Clemson University Built Environment Laboratory (BEL). The lab is equipped with closed-loop hydraulic and screw-driven actuators for applying loads, a universal test machine for testing small components, and data acquisition equipment to measure and record stresses, loads, accelerations, and deformations.

Field deployment of the device on wild alligators was performed at multiple sites throughout the alligator range in North Carolina, South Carolina, Georgia, and Texas. In North Carolina, we captured alligators in freshwater canals at Lake Waccamaw, Columbus County, and throughout Lake Ellis Simon, Craven County. Both locations represent typical freshwater habitats for alligators in North Carolina and are described in detail by Stager and Cahoon (1987) and Fuller (1981). In South Carolina, we captured alligators in natural and impounded wetlands, including freshwater and brackish areas, at the Tom Yawkey Wildlife Center, Georgetown County (Wilkinson et al. 2016), Santee Coastal Reserve, Charleston County (Rhodes and Lang 1995), Nemours Plantation, Beaufort County (McGregor et al. 2009), Spring Island, Beaufort County (Kidd-Weaver et al. 2022), and Par Pond, Aiken County (Gibbons and Sharitz 1981). We conducted alligator sampling in Georgia in collaboration with the Jekyll Island Authority from freshwater and brackish impoundments on the Jekyll Island Golf Club, Glynn County (Rosenblatt et al. 2023). Finally, we captured alligators in Texas on the Welder Wildlife Refuge, San Patricio County, from both natural freshwater wetlands (i.e., an oxbow of the Aransas River) and artificial water retention ponds (i.e., cattle tanks; Drawe et al. 1978).

## METHODS

We designed 2 versions of the crocodylian jaw prop: a medium-duty device (MDD) for use on alligators <250 cm total length (TL) and a heavy-duty device (HDD) for alligators  $\geq$ 250 cm TL. Our device design is comprised of 3 main components: vertical threaded rods (upright supports), locking nuts, and horizontal bars (cross-members; Figure 2). We constructed the MDD with flat bar cross-members and the HDD with square cross-members. For each version, the vertical threaded rod components and locking nuts remained constant. The choice of materials was based primarily on availability and cost, which we estimated as \$133/device (Table 1). We purchased all materials from McMaster Carr (Douglasville, GA, USA), and the Clemson University Machine Shop machined the components to the specified lengths. During field applications, we used cyanoacrylate glue to add strips of cork matting to the surfaces of the cross-members to reduce impact on alligator teeth. The inclusion of padding is optional and up to user discretion and is not included in the total device cost. We maintained the device by periodically oiling the parts with nontoxic mineral oil. Some surface rust did occur but did not affect device performance.

We performed mechanical tests of the devices using a 50 kN capacity Universal Testing Machine (UTM). Because crocodylian bite force increases linearly with size (Erickson et al. 2003), we varied the aperture (vertical distance between the horizontal cross-members) to mimic the variation of a crocodylian's gape (Erickson et al. 2003). We also changed the spread (distance between load application points on the horizontal cross-members) to



**FIGURE 2** Description of the heavy-duty metal jaw prop device (left) and the medium-duty metal jaw prop device (right) designed for keeping crocodilian jaws open. The 2 devices are depicted at a 16 cm aperture with components and component lengths indicated. Dashed lines show the variation in aperture and spread applied to the devices during the initial strength testing phase.

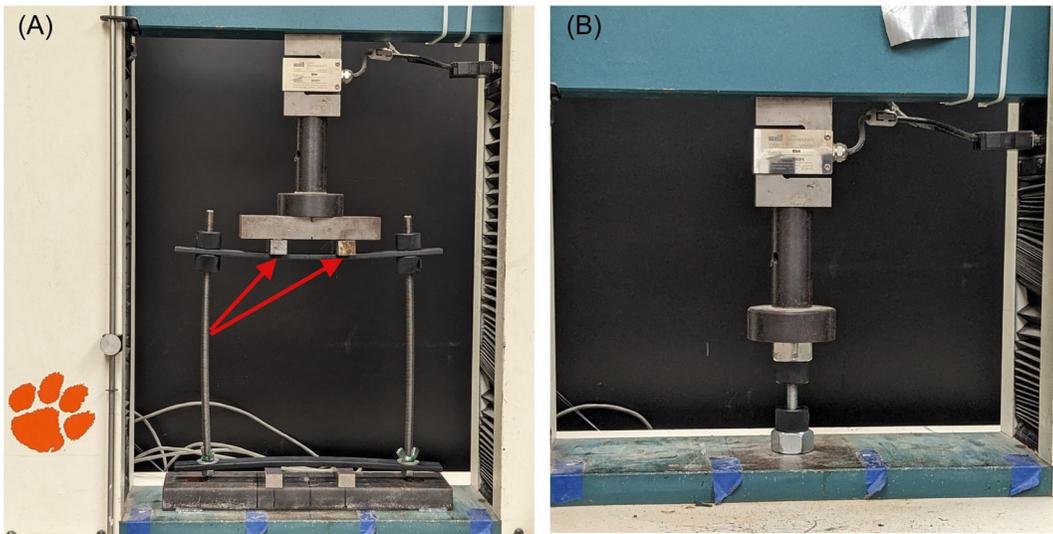
simulate different skull widths as would be encountered with different body sizes and species of crocodilians (Erickson et al. 2003). We measured the aperture from the inside of the cross-members and spread from the center of the applied loads. As such, we designed the MDD for use with smaller alligators (or crocodilians) with smaller jaws and tested it at spreads of 8 and 12 cm. We tested the HDD, intended for larger alligators, at spreads of 12 and 15 cm. We tested each device and spread combination at 3 apertures of 8, 16, and 24 cm, respectively, intending to cover a range of realistic gape sizes (Figure 2). During testing, we applied a load (force in kN) to the top and bottom cross-member through 1.3 cm wide square steel bars (Figure 3).

The purpose of the initial mechanical test was to apply forces to each device that approximated the load from a realistic alligator bite as informed by the range of caniform bite forces (1.4 to 6.1 kN) reported by Erickson et al. (2012). We loaded the MDD with a force of 2.56 kN at each aperture and spread and the HDD with a force of 8.90 kN at each aperture and spread. During testing, the UTM measures the displacement or deflection of the device, measured in millimeters (mm). The UTM also measures the force applied to the device (kN). The initial loading level was meant to approach the force required to deform the cross-members (i.e., yield) permanently. The yield of a material is the point at which the force applied results in plastic deformation of the material (permanent distortion).

After the initial loadings, we set each device to an aperture and spread of 12 cm and applied load until device failure. We kept the spread and aperture consistent between devices during the final failure tests for easier comparison. The slide adjust nuts are the mechanism by which force transfers from the cross-members to the vertical threaded rods. Typical nuts have threads that allow the nut to transfer forces greater than the capacity of

**TABLE 1** Device Component details for the crocodilian jaw prop device for the medium-duty device (flat rod) and heavy-duty device (rectangle tube). The quantity of each component is shown in parentheses beside the component. Specifications and yield stress were not specified (NS) for many components. Available yield stress for the threaded rod and flat rod are presented in megapascals (MPa). Labor costs included machining to cut components to length, drilling holes in cross members, and grinding and polishing edges. Labor costs could be reduced if users choose to machine the components independently.

Component	Material	Specification	Yield stress	Dimensions	Unit cost (USD)
Threaded Rod (2)	316 Stainless steel	NS	482.6 MPa	9.53 mm; 16 thread	\$6.94/30 cm
Flat rod (2)	Low-carbon steel	Grade 1018	372.3 MPa	25.4 × 6.25 mm	\$7.48/30 cm
Rectangle tube (2)	Low-carbon steel	ASTM A513	NS	19.05 × 19.05 mm	\$7.50/30 cm
Push button slide adjust nut (4)	Steel	NS	NS	9.53 mm; 16 thread	\$12.98 ea
Wing nut (2)	18-8 Stainless steel	NS	NS	9.53 mm; 16 thread	\$0.86 ea
Hex nut (4)	18-8 Stainless steel	ASTM F594	NS	9.53 mm; 16 thread	\$0.13 ea
Labor cost (machining) by the Clemson University Machine Shop at \$59/hour					\$50/device
Medium-duty device total cost					\$133.00
Heavy-duty device total cost					\$133.04



**FIGURE 3** Testing setup for the metal jaw props used for holding crocodilian jaws open and slide adjust nuts as components of the jaw props. (A) The medium-duty metal jaw prop is set at 24 cm aperture and 8 cm spread. The red arrows indicate the 1.3 cm wide square steel bars that apply a spread of force on the cross-members and mimic points of contact for crocodilian jaws. (B) The testing setup for the slide adjust nuts. The testing setup allows the downward application of force onto the threaded rod to test both nuts individually and simultaneously.

the threaded rod; however, the slide adjust nuts are only partially engaged around each threaded rod. To determine at what point the slide adjust nuts would fail, we developed a test setup to test the capacity of 2 nuts simultaneously. In this setup, a short length of threaded rods connects 2 slide-adjust nuts, which sit between large traditional nuts. We applied a compressive force to the top nut to transfer the force through the slide adjust nut above, through the threaded rod, and into the slide adjust nut below. This setup allowed the threaded rod to push through the nuts at the top and bottom without contacting the loading frame or load cell (Figure 3).

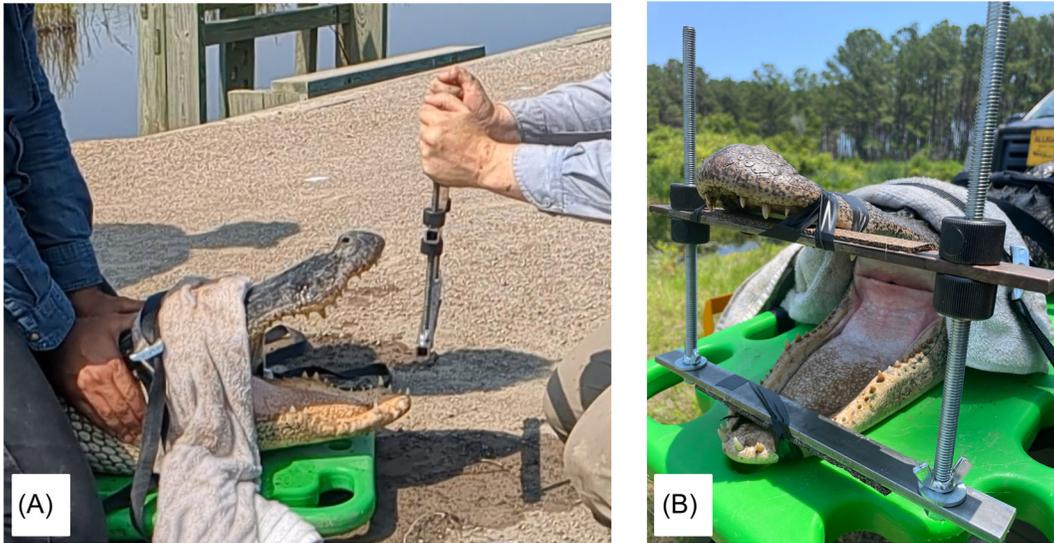
## Field testing

To test the practical application of the jaw prop in the field, we evaluated the devices on wild alligators. We captured alligators using snatch hooks or cable snares (Webb and Messel 1977, Wilkinson et al. 2016). Once captured, we minimized stress on animals by applying an eye covering and taping the jaws closed using electrical tape. We then transferred alligators to a rigid medical spine board and restrained their bodies with adjustable cam-straps. Once secured, one team member straddled the neck of the alligator to minimize lateral head motion. A second team member then untaped the alligator's snout and encouraged the alligator to open its jaws by lightly tapping the dorsal surface of the snout tip using a stick. The team member in charge of device deployment determined the aperture of the device by the gape of the alligator and used the slide adjust nuts to set the device. The device is inserted swiftly downward and into the mouth of the alligator in the approximate area of the premaxilla (anterior to the caniform teeth), contacting the mandible first before the animal's top jaw (premaxilla) almost simultaneously closes onto the top cross-member. The device is then secured by taping the top and bottom jaws to the top and bottom cross-members, respectively (Figure 4). After securing the device, the user adjusted the device aperture by tightening or loosening the slide adjust nuts to raise or lower the top cross-member.

To remove the device, we repeated the same general process as described above but in reverse. During device recovery, we placed a solid piece of wood on the edge of the bottom jaw as a failsafe to mitigate bite risk if recovery failed. If required, we reduced the aperture of the device by sliding the nuts down. The electrical tape was removed by the team member who deployed the device while pressure was applied to the alligator's cranium (by the person straddling the neck) to hold the device in place. Once the tape was released, the alligator was encouraged to open its mouth, or the deployment team member opened the mouth by gently lifting the top jaw at the tip of the snout with a rope, allowing the device to be tipped forward and lifted clear of the mouth. In all device deployment and recoveries, we kept our hands on top of the snout, clear of the sides of the mouth, or protected by the vertical uprights and cross-members of the device to limit bite risk.

## RESULTS

We successfully used the devices on 100% of the 76 deployments on alligators from May to October 2023. Alligators ranged in total length (TL) from 121 to 329 cm. We used the MDD in 61 deployments where alligators were <240 cm TL ( $\bar{x}$  = 185.2, SE = 4.1, min-max = 120–233) and the HDD for 15 total deployments of alligators  $\geq$ 240 cm TL ( $\bar{x}$  = 271.6, SE = 6.4, min-max = 241–329). During deployment and recovery, the devices showed no signs of deflection (bend) in the cross-members and uprights. We observed moderate damage (e.g., chipping or breakage) to alligator teeth during device deployment and recovery. We recorded limited impact to 1–2 teeth on the top and bottom jaw during some deployments as the width of the cross-members is such that it generally makes direct contact with one tooth at each contact point. However, we did not notice any damage in the majority (>90%) of deployments.

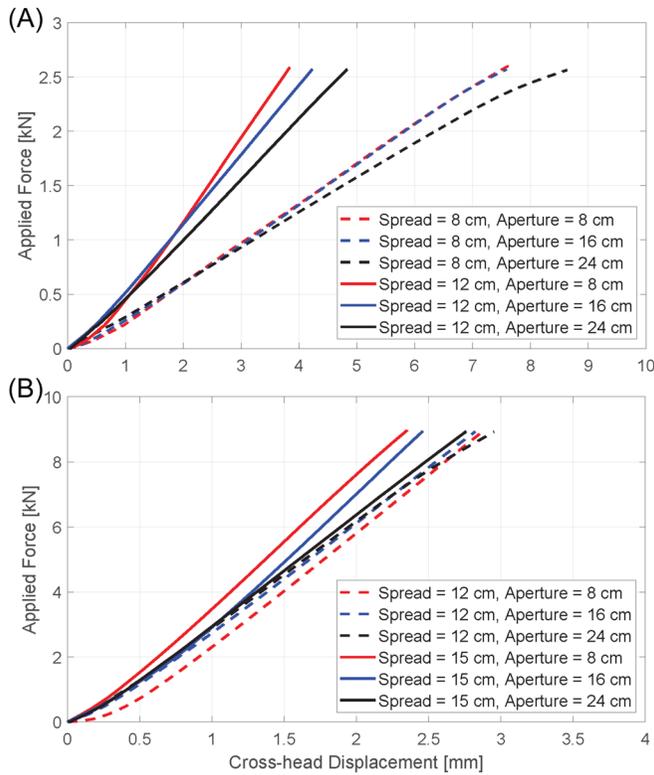


**FIGURE 4** (A) Heavy-duty metal jaw prop being used in situ to hold the jaws open of an adult American alligator (*Alligator mississippiensis*) >250 cm TL (June 2023). Device deployment is performed with the hands of the deployer gripping the top of the device uprights, keeping the hands away from the open mouth of the alligator. The device is inserted swiftly downward and into the mouth of the alligator in the approximate area of the premaxilla (anterior to the caniniform teeth), contacting the mandible first before the animal's top jaw (premaxilla) almost simultaneously closes onto the top cross-member, keeping the jaws from closing. The device is then secured by taping the top and bottom jaws to the top and bottom cross-members, respectively. (B) The medium-duty metal jaw prop is being used in situ with an adult alligator <250 cm TL (June 2023). Note the cork padding on the horizontal cross bars and the device taped into place on the upper and lower jaws.

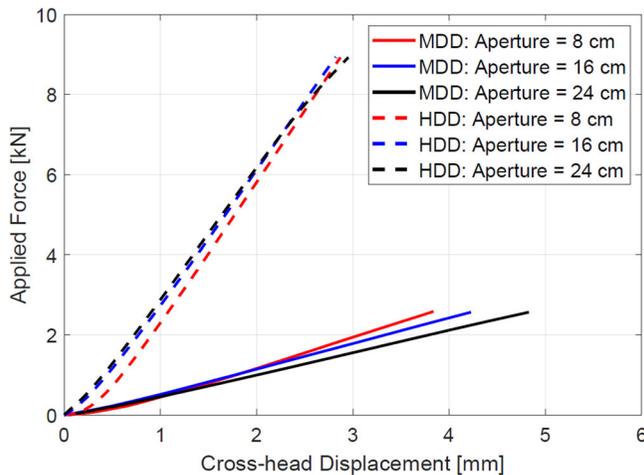
## Initial strength testing

In the initial mechanical testing phase, we loaded both the MDD and HDD to 2.56 kN and 8.90 kN, respectively, to determine the effect of the aperture and spread on the stiffness of the device. All initial tests indicated that the load applied did not cause permanent deformation in the device as the force-displacement response remained approximately linear for the applied load (Figure 5), and minimal deformation was measured after the load was removed. The average residual displacement of the cross-members of the MDD was 0.47 mm (SE = 0.87, min-max = 0.18–0.83) and 0.24 mm (SE = 0.35, min-max = 0.14–0.37) for the HDD jaw prop. The effect of spread is far more pronounced in the MDD than in the HDD due to the structure of the cross-member. The results indicated that as the aperture increases, the deformation measured also increases (Figure 6). This result was expected as the increased length of the vertical threaded rods increases their susceptibility to bending. Additionally, the deformations decreased as the spread of the load increased. This result was also expected as the induced bending in the cross member reduces as the load application points spread further apart.

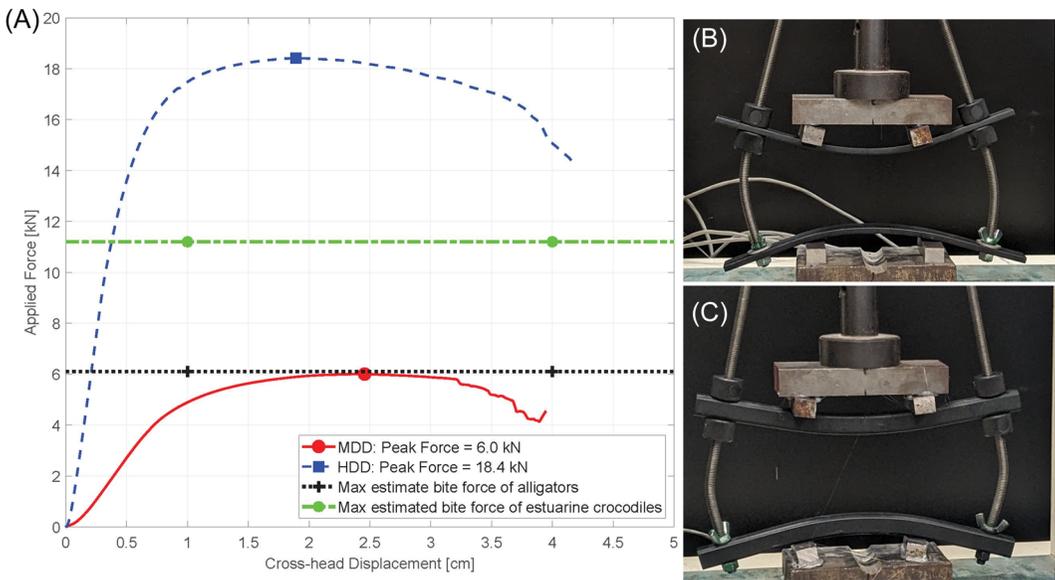
Finally, the displacement measured in the HDD was less than the MDD for the same aperture (8 cm, 16 cm, and 24 cm) and spread (12 cm). A comparison of the force-displacement response at a 12 cm spread for both devices reveals the dramatic increase in stiffness of the HDD compared to the MDD (Figure 7). It is important to note that we applied force vertically on the device during testing deployment. Results would differ if the angle of force were not aligned vertically and would likely decrease the devices' stability and ability to resist the load applied. Proper placement is an essential consideration for the deployment and use of the device in field applications.



**FIGURE 5** Results of the initial testing phase for (A) medium-duty crocodilian jaw prop device loaded to a maximum of 2.56 kN and (B) heavy-duty crocodilian jaw prop device loaded to a maximum of 8.90 kN for the range of aperture (vertical opening) and spread (horizontal force loading) for each device.



**FIGURE 6** A comparison of the deflection of the medium-duty metal crocodilian jaw prop (MDD) and the heavy-duty metal crocodilian jaw prop (HDD) with the same aperture (8 cm, 16 cm, 24 cm) and spread (12 cm). Results show that the stiffness of the HDD is 3 times greater than that of the MDD.



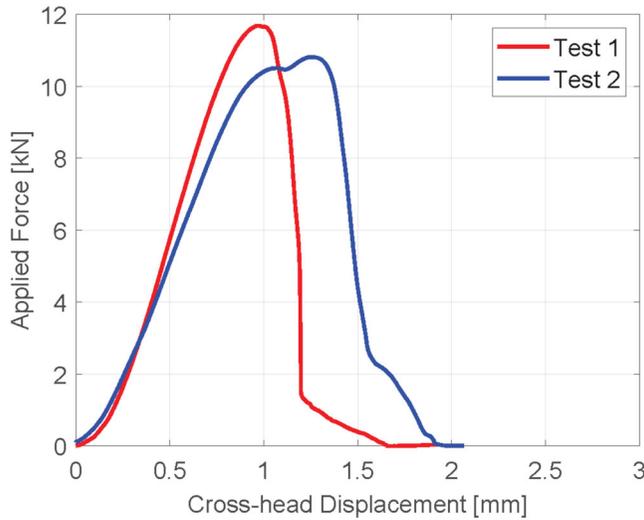
**FIGURE 7** (A) Results of trials to assess the maximum capacity to hold the jaws of crocodylians open of the medium-duty metal jaw prop (MDD) and heavy-duty metal jaw prop (HDD) jaw props set at 12 cm spread and 12 cm aperture. The fine black dashed line denotes the maximum estimated caniniform bite force of American alligators (*Alligator mississippiensis*) of 6.1 kN, and the coarse green dashed line represents the maximum estimated bite force for crocodylians from estuarine crocodiles (*Crocodylus porosus*) of 11.2 kN (Erickson et al. 2012). The pictures on the right show the deformation and extent of component yield for the HDD (B) and MDD jaw prop (C).

## Maximum capacity testing

We tested the maximum capacity of both devices by testing them to failure at a 12 cm aperture and 12 cm spread for comparison. The displacement rate of the tests was 2.54 mm/min (0.1 in/min). Strength and stiffness between devices varied and indicated that the HDD was approximately 3 times stronger and 6 times stiffer than the MDD (Figure 7). The dashed lines on the figure denote the maximum caniniform bite force reported by Erickson et al. (2012) for alligators ranging up to 372 cm TL and estuarine crocodiles (*Crocodylus porosus*; strongest measured bite force) up to 459 cm TL. Our mechanical testing demonstrated the capacity of the device to withstand alligator caniniform bite forces that exceeded current reported values.

During the maximum capacity testing, we observed considerable deformation of the cross-members and vertical threaded rod members of both devices. Deformation indicates that some rotation was transferred between the cross-members and the vertical threaded rods through the connections. We observed permanent deformation in both cross-members of 2.65 cm for the MDD and 3.48 cm for the HDD at the conclusion of the test, which was not present in the initial testing phase. We stopped each maximum capacity test when the devices had excessive deformation and forces dropping below 80% of the peak force level, indicating failure, but we observed no rupture of any device components during testing. The deformations observed during the failure test suggested that a significant amount of deformation (>2 cm) occurs in the device before reaching the peak load. Thus, deformation gives the user an indication that the device is approaching its capacity before the rupture of any of the components occurs.

The failure of the slide adjust nuts resulted in damage to the portion of the rod threads engaged in the slide adjust nut. Two tests performed on 2 sets of slide adjust nuts with force-displacement responses indicated the average capacity of the slide adjust nuts was 11.25 kN (Figure 8). The 2 nuts supporting the top cross-member can



**FIGURE 8** Results of repeated maximum capacity tests of the push button slide adjust nuts used on the metal crocodilian jaw prop devices. The curves present results from 2 tests on 4 total slide adjust nuts. The testing setup is described and pictured in Figure 3.

support 22.5 kN of force, which is greater than the maximum force endured by the HDD, indicating that the device experienced failure of cross-members before failure of the slide adjust nuts.

## DISCUSSION

A prerequisite for handling crocodilians is equipment to effectively limit bites by controlling an animal's jaws. Though much work with crocodilians requires a safely closed and secured snout, some tasks necessitate access to the inside of the mouth. Such work demands the need for appropriate tools that can hold crocodilian jaws open and secure while optimizing access to the oral cavity and associated structures. We developed a tool to allow safe and effective access to the crocodilian oral cavity, palatal valve, pharyngeal cavity, and esophagus across a range of sizes. Our 100% successful deployment of the device across a range of alligator sizes demonstrates the device's efficacy as a reliable and adaptable tool for access to the oral cavity. We are confident the device could be used effectively by other wildlife professionals and with other crocodilian species.

Mechanical testing of the devices and their components demonstrated that the device design can withstand the caniform bite forces of alligators and other crocodilians (Erickson et al. 2012). Although the aperture of the device and the spread of force affect the degree of deflection in the device, our tests indicated that the tools can safely withstand crocodilian-specific loads at all tested apertures and spreads. However, future users should consider what device version may be most appropriate for the species and size of the crocodilian with which they are working. The work by Erickson et al. (2012) is a good reference to consider when determining which device version (MDD or HDD) aligns more appropriately with recorded crocodilian bite forces. We designed and tested our devices on a particular target species and body size, i.e., American alligators <350 cm TL. Other crocodilian species may necessitate adaptations to the device design we present here. Slender-snouted crocodilian species may not require the exact lengths of horizontal cross-members as used in our design. Conversely, though the HDD could theoretically withstand measured caniform biteforces for the largest crocodilian species (estuarine and Nile crocodiles [*Crocodylus niloticus*]), individuals of other crocodilian species may have head sizes that exceed the width

and aperture of our device. As such, it may be necessary to scale up the overall size of the device and materials used. The vertical threaded rods, cross-members, and slide adjust nuts all come in larger specifications that, following our design, could potentially accommodate even the largest crocodylians. The slide adjust nuts we used on the device demonstrated adequate resistance to forces applied during testing. While this result indicates that the slide adjust nuts are sufficient to achieve the full strength of the device, the combined capacity of 2 slide adjust nuts, one on either side, is only 22% greater than the tested capacity of the HDD. Given that the failure of the slide adjust nuts is likely to be both more sudden and dangerous than the failure of the cross-members or vertical threaded rods, users should consider this, especially if future device versions use stronger cross-members.

Regarding safety when using the metal jaw prop device described herein, we offer the following considerations. The structure and design of our tools are intended for the vertical application of force directly down onto the device cross-members and through the vertical supports. We do not recommend deploying the instrument at an angle. When this happened in the field, we paused activities and repositioned the device to optimize device strength and minimize potential risks. In addition, we added a threaded hex nut to the vertical rods in between the lower slide adjust nut and the terminal wing nut on the lower cross-member. We adjusted this hex nut to leave at least a 5 cm gap between the 2 cross-members as a fail-safe in case of unexpected device failure. This aperture is sufficient to prevent the device from entirely collapsing and crushing a hand or limb during work performed within the oral cavity. Additionally, although we rarely observed alligator tooth damage while using the device, we added an organic cork padding to the outer surfaces of the cross-members to protect animals' teeth. In other applications, alternative materials (e.g., electrical tape, silicone matting, rope) could be used to increase the amount of padding and further mitigate tooth damage. However, future users should consider that deeper padding may cause the device to stick to or become lodged between teeth and potentially make device removal more complex.

## RESEARCH IMPLICATIONS

The aim of our project was the development of a tool for holding open the jaws of alligators to facilitate the collection of stomach contents by gastric lavage. However, the device has further research applications and implications as it optimizes access to the oral cavity and associated structures beyond the palatal valve, providing novel opportunities for various investigations related to crocodylian anatomy, morphology, and physiology. Also, with limited obstruction within the mouth, more detailed observations and safer collections of ectoparasites are possible. In addition to research, there are also applications for veterinary and management work as well. Wildlife managers working with crocodylians called upon to rescue or relocate crocodylians may be required to remove foreign objects (e.g., fishing tackle) from an animal's mouth, palatal valve, or throat, and this device provides safe access to these areas. Moreover, the device may be helpful in captive settings for a variety of veterinary procedures and assessments, as demonstrated by the DWA and the acrylic jaw prop. Finally, the device is compact, transportable, and useable on crocodylians of different size classes. These characteristics position this jaw prop device favorably for use in research beyond the application it was initially designed for (i.e., gastric lavage). However, all equipment has limitations, and its application for all species of crocodylians is undefined. We hope that the development of this jaw prop leads to further testing and exploration of its applicability to crocodylian research and management in both the field and in captivity.

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### CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

### ETHICS STATEMENT

This project adheres to the standards of safe capture and handling of crocodilians as approved by the Clemson University Animal Use Protocol #2022-0454 and techniques vetted by the International Union for the Conservation of Nature Crocodile Specialist Group. Further permissions were secured through research permits from the South Carolina Department of Natural Resources and the Georgia Department of Natural Resources (#1001742080). Alligator sampling in North Carolina and Texas was done under approval and in participation with the North Carolina Wildlife Resources Commission and the Texas Parks and Wildlife Department.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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