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NOTE

Marine Mammal Science

Suspected broadhead arrow injuries in two common bottlenose dolphins (*Tursiops truncatus*) along the Alabama Coast

Merri K. Collins[1] | Ruth H. Carmichael[1,2] | David S. Rotstein[3] | Jason H. Byrd[4] | Alissa C. Deming[1]

[1]Marine Mammal Research Program, Dauphin Island Sea Lab, Dauphin, Island, Alabama

[2]University of South Alabama, Department of Marine Sciences, Mobile, Alabama

[3]Marine Mammal Pathology Services, Olney, Maryland

[4]University of Florida, Department of Pathology, Immunology and Laboratory Medicine, Gainesville, Florida

Correspondence
Merri K. Collins, 101 Bienville Boulevard, Dauphin Island, AL 36528.
Email: mcolli9@masonlive.gmu.edu

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The common bottlenose dolphin (*Tursiops truncatus*) is one of the most frequently stranded cetaceans globally, and because these animals inhabit a wide variety of marine habitats, this species has a high risk of interactions with humans (Bejder, Samuels, & Whitehead, 2006; Byard, Gilbert, & Kemper, 2001; Byard, Kemper, & Bossley, 2007; Constantine, Brunton, & Dennis, 2004). In the United States, from 2000 to 2018, the National Ocean and Atmospheric Administration's (NOAA) Marine Mammal Health and Stranding Response Program (MMSHRP) database shows that bottlenose dolphins accounted for 78% (11,295/14,532) of all cetacean strandings. The coastal ecotype of bottlenose dolphin inhabits coastal oceanic bays, sounds, and estuaries, bringing them into close contact with humans and associated anthropogenic activities (Vollmer & Rosel, 2013). Some dolphins have been documented to select habitats with relatively high human presence (López, 2018; Powell, Machernis, & Engleby, 2018), and many people interact with dolphins despite laws or enforcement efforts intended to restrict these interactions (Marine Mammal Protection Act of 1972; Cunningham-Smith, Colbert, & Wells, 2006; Powell et al., 2018). Human-dolphin interactions can include hand feeding, feeding-related vessel following, contact with fishing gear, intentional harm, and mortality (Byard et al., 2007; Samuels & Bejder, 2004; Vail, 2016). Depredation by dolphins can cause contentious relationships between fishermen and dolphins that can result in retaliatory actions toward the animals (Finn, Donaldson, & Calver, 2008; Powell & Wells, 2011; Samuels & Bejder, 2004).

In the United States since 2016, NOAA's National Marine Fisheries Service has required Stranding Networks to document human interaction as part of baseline data collection (Level A data) for all marine mammal strandings (https://www.fisheries.noaa.gov/marine-mammal-protection). Presence of fishing gear or obvious signs of external trauma (i.e., net impressions or lacerations on the skin, gunshot wounds, propeller wounds, punctures) can provide evidence of human interaction, but human interactions also can be subtle and difficult to clearly identify. In these cases, human interactions are documented as “cannot be determined” in initial stranding reports (Moore et al., 2013).

Additionally, evidence of human interaction can be obscured by ante- and postmortem changes, including tissue decomposition, carcass scavenging, and rake marks (due to conspecific or interspecific interaction), or it may not be detected due to a lack of training or experience of the examiner (Moore et al., 2013). As a result, the number of documented human interactions is likely conservative (Moore et al., 2013).

In Alabama, human interaction is particularly high for the relatively small (965 km) tidal coastline in comparison to other northern Gulf of Mexico (nGOM) states, such as Mississippi and Louisiana, which have longer coastlines and more annual cetacean strandings but fewer human interaction cases (MMSHRP 2019). From 2011 to 2018, 82% (256/312) of cetacean strandings were bottlenose dolphins, with nearly 20% (45/256) having documented human interactions including fishery interactions, intentional harm, and gear or debris entanglement. This research evaluated two dolphin carcasses that stranded in Alabama in 2016 (Case 1) and 2018 (Case 2) that had similar, distinct X-shaped skin lesions from an unknown source. To evaluate potential sources of these distinct X-shaped skin lesions, we analyzed trends in fisheries and cases of intentional harm in the nGOM through a literature and stranding database review. Forensic analysis of impression patterns of potential weapons and objects that can make similar markings were examined using clay casts, and testing was conducted on a dolphin carcass to evaluate likeness of the impressions to lesions in these cases. Photos of the X-shaped lesions were examined and compared with human medicolegal cases, and tissues from the 2018 animal were collected during gross necropsy, fixed in 10% neutral buffered formalin, and evaluated microscopically by a board-certified veterinary pathologist (D. S. R.) to determine if they were inflicted before or after death.

Case 1 was a 236 cm, adult male bottlenose dolphin carcass recovered on 6 October 2016 in Fort Morgan, Alabama, on the southeastern shore of Mobile Bay. The dolphin was in a good nutritional plane, moderately decomposed (Late Code 3; Geraci & Lounsbury, 2005) and had two sections of rope with cut, frayed ends encircling the cervical and thoracic regions of the carcass. The rope was analyzed by NOAA National Marine Fisheries Service Gear Research Team (W. Hoggard and K. Falana) and determined to be a 9/16″ polydacron sinking line, used in shrimp fisheries, and commonly used as anchor line. The tissue surrounding the rope had superficial rope-impressions with dark discoloration on the skin and associated blubber. Additionally, there were indications of fishery interaction by net and subsequent entanglement, including two linear abrasions at the left and right fluke insertion and six undigested fish (Gulf menhaden, *Brevoortia petronus*) in the forestomach. There was a 2 cm × 2 cm X-shaped lesion on the right lateral body, just dorsal to the trailing edge of the right pectoral fin (Figure 1a). The wound had slightly rounded margins and extended through the blubber, stopping at the underlying muscle. The remaining findings on gross examination were unremarkable. Due to advanced autolysis, histological evaluation was not performed. The cause of death was not definitively determined, however, peracute underwater entrapment (drowning) is considered as the most probable cause of death based on gross necropsy findings.

Case 2 was a 189 cm, subadult, male bottlenose dolphin carcass recovered on 3 March 2018, in Fairhope, Alabama, on the northeastern shore of Mobile Bay. The dolphin was emaciated and moderately decomposed (Late Code 3; Geraci & Lounsbury, 2005). This animal had two X-shaped lesions on the skin that extended through the blubber, stopping just before the skeletal muscle. Lesion A was located on the right lateral peduncle, and lesion B was located on the right lateral body just caudal to the right pectoral fin (Figure 1b,c). Both lesions were 1.8 cm × 1.8 cm, had rounded margins, and extended through the blubber layer but did not involve underlying skeletal muscle. Full histological evaluation was performed on all major organs, including the X-shaped lesions. Histological examination showed both X-shaped lesions had moderate edema, extravasated erythrocytes (bruising), and inflammatory cells (Figure 2), indicating acute lesions that occurred hours to days prior to death. Additional histological findings included chronic pulmonary nematodiasis and cutaneous lesions involving 25% of the epithelium and characterized by exuberant epibiotic growth with underlying dermal erosion. These latter skin lesions are consistent with exposure to freshwater water and match those described by Colbert et al. (1999). The cause of death was not definitively determined, but prolonged freshwater exposure is considered the most probable cause of death based on gross necropsy findings.

Given the similarity between the X-shaped lesions in both cases including size, shape, and location of the lesions on the body, these lesions were suspected to be a pattern injury (a lesion from the same or similar source). Due to the linear shape, these lesions were initially suspected to be associated with fishery interaction such as entanglement

FIGURE 1 Comparison of X-lesions to typical fishery interactions, scavenging, postmortem carcass testing, and cases of intentional harm. (a) Magnified X-lesion in Case 1 on right craniolateral body, scale bar = 1 cm. (b) Magnified X-lesion in case 2 on right dorsal peduncle, scale bar = 1 cm. (c) Magnified X-lesion in Case 2 on right lateral body, scale bar = 1 cm. (d) Superficial X-shaped mark on the peduncle of a dolphin from net entanglement, scale bar = 1 cm. (e) Abrasions along the caudal peduncle/fluke insert from net entanglement. (f) Linear lacerations from net entanglement along rostrum of a dolphin. (g) Linear lacerations along the dorsal fin from net entanglement, scale bar = 1 cm. (h) postmortem scavenging mark on dolphin carcass attributed to shorebirds. (i) Resulting lesion of 4-point broadhead arrow tip impaled in to dolphin carcass for lesion comparison, scale bar = 1 cm. (j) Broadhead arrow wound on the cranium of a dog, photo provided by A. Cook/Jackson Co. Floridian. (k) Broadhead arrow entry wound on a thoracic cavity of a bull moose, photo provided by J. Lawrence.

or entrapment in a shrimp trawl net or gill net as described by Moore et al. (2013). Upon further comparison to fishery interaction injuries, the lesions were found to be unlike typical markings caused by monofilament gill net or other known net entanglement lesions. Net entanglements are known to result in superficial X-shaped impressions on the skin (Figure 1d; Moore et al., 2013) or linear lacerations most often at the base of appendages (fluke insertion; Figure 1e dorsal fin; rostrum; Figure 1f, dorsal fin; Figure 1g). The X-shaped lesions in these cases were also deeper than net entanglement or entrapment marks associated with acute drowning and were located along the lateral body wall rather than the appendages.

Postmortem scavenger markings were also a suspected origin of the X-shaped lesions. Scavenging marks from birds and sharks can result in atypical marks on decomposing dolphin carcasses, often grouped together in clusters on areas of the body that are exposed when the carcass strands. Comparisons to known shorebird and shark scavenging marks on other carcasses (Figure 1h) did not show the same pattern of lesions observed in these cases. Additionally, histological evaluation of the lesions in Case 2 determined there was tissue reaction, indicating the lesions occurred prior to death. These findings suggested that the X-shaped lesions observed in Cases 1 and 2 were less likely to be the result of scavenging or fishery net interaction and further work exploring the possibility that lesions were associated with intentional harm was conducted.

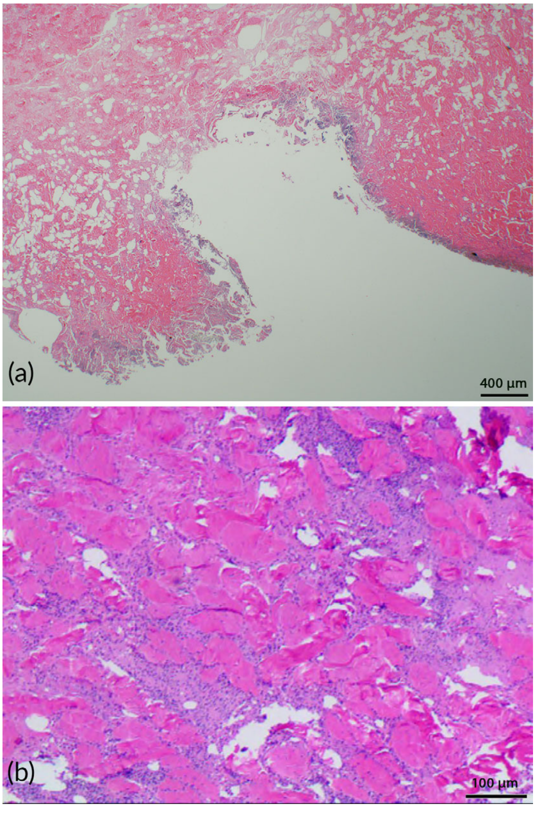

FIGURE 2 H&E section of skin and blubber from the X-shaped lesions on the right lateral body of Case 2 (lesion B; Figure 1e). (a) The epithelium is absent and there is a U-shaped indentation of the dermis. Dermal collagen bundles are separated by clear spaces (edema). 200×. Bar = 400 μm. (b) Within the dermis, there are neutrophils and cellular debris separating collagen bundles; disruption, neutrophils, and inflammatory cells shown around dermal defect. 100×. Bar = 100 μm.

Objects with potential to leave X-shaped impact patterns in soft tissue include spearfishing tips and broadhead hunting arrows (Byard et al., 2001; DiMaio & DiMaio, 2001). Fishing spears and harpoons are equipped with a single edged blade, leaving a singular, oval penetrating wound on associated animals and was ruled out as the source of the lesions (Byard et al., 2007; Sung, Kesha, Hudson, Root, & Hlavaty, 2018). When comparing lesions to documented forensic case studies, we found that in human and animal cases, four- to five-point broadhead arrows were identified as the weapon responsible for causing X-shaped lesions (DiMaio & DiMaio, 2001) and broadhead arrow wound patterns mimic the number and arrangement of blades on the arrow tip (1–6 blades; Smith-Blackmore & Robinson, 2018; Sung et al., 2018).

We tested the potential for a broadhead arrow to have caused the X-shaped lesions in Cases 1 and 2 by comparing impression size and shape of five commonly available variations of arrow tips (standard Muzzy Phantom fixed blade 125 grain broadhead 4-point tip, Muzzy Trocar 4-point hybrid mechanical broadhead, and Wac'Em Archery 4 blade fixed broadhead 100 grain: Feradyne Outdoors, Superior, WI; Bowtactix judo broadhead: Johns Creek, GA; Newland hammer broadhead: Dongguan, China). Silicone modeling clay (Polly Plastics, Saginaw, MI) was used to make impressions of the shape of various broadhead arrow tips to mimic impalement seen in these cases. Two broadhead arrow tip variations (the standard Muzzy Phantom fixed blade 125 grain broadhead 4-point tip and Muzzy Trocar 4-point hybrid mechanical broadhead tip; Feradyne Outdoors, Superior, WI), had a close match to the lesions observed in Case 1 and 2, leaving 2 cm × 2 cm prominent X-impressions.

To corroborate the pattern injury in dolphin tissue, the size and shape-matched tips were then used to penetrate the left dorsolateral body and peduncle regions of two carcasses that were in a moderate state of decomposition (Code 3). Carcasses were stabbed by hand with the arrow tips attached to a Beman arrow shaft (Beman USA, Salt Lake City, UT) due to the inability of duplicating the situational and environmental conditions (e.g., distance from target, skill of shooter, strength of crossbow) in which an animal may have been shot in situ. The Muzzy Trocar did not penetrate the left lateral body or peduncle region of the animal when force was applied by hand. The Muzzy Phantom penetrated the blubber layer resulting in a distinct X-shaped impression 2 cm long and 2 cm wide, making it the closest match in size and shape to the X-shaped lesions on Cases 1 and 2 (Figure 1i). While the skin on lesions in Case 1 and Case 2 were markedly more agape than the thin incised lesions made by hand on the test carcasses, gaped wounds have been documented in broadhead arrow injuries due to decomposition and healing (Bradley-Siemens, Brower, & Kagan, 2018) or entry direction (Sung et al., 2018).

After consideration of possible sources for the X-lesions (fishery interactions, postmortem scavenging and decomposition, spearfishing tips, broadhead arrows) a broadhead arrow pattern injury was the most consistent with the size, shape, and location of the X-lesions documented in the Alabama cases. Broadhead arrows are inexpensive, easily obtained, and marketed in many brands and modifications for small game or bowfishing (Sung et al., 2018). Although broadhead arrows can cause wounds that extend into the skeletal muscle, shallow penetration injuries by a broadhead arrow have been documented in animals. In 2015 in Florida, a dog shot in the head with a broadhead arrow survived the injury because the arrow did not puncture the skull and only penetrated cranial soft tissue (Buckhalter, 2015; Figure 1j). In contrast, during 2014, a dolphin was shot at close range from shore with a big game broadhead hunting arrow in Orange Beach, Alabama. The arrow penetrated deep within the epaxial muscle and into the thoracic cavity, leading to that animal's death ("Pregnant Wild Dolphin," 2014; Stein, 2014). Due to the superficial nature of the X-shaped lesions in both cases, it is unknown if the animals were shot directly, or stabbed by hand using an arrow as a deterrent if the animals were near a net or boat. Although it does not seem plausible that a high-power crossbow would fail to penetrate the body cavity, variation in the depth of penetration in broadhead arrow injuries can occur due to the type of bow used (compound, recurve, crossbow), skill-level of the shooter, distance from the target, blade age and sharpness, strength or movement of the target animal, and angle of entry, and environmental variables such as water slowing the velocity of the arrow (Figure 1k; Smith-Blackmore & Robinson, 2018).

Dolphins conditioned to human presence, and illegal feeding are particularly vulnerable to harm (Byard et al., 2001, 2007; Cunningham-Smith et al., 2006; Finn et al., 2008). Hunting is a popular sport, with nearly 580,000 registered in- and out-of-state hunters in Alabama alone during 2018 (United States Fish and Wildlife Service, 2018), thus hunting equipment such as guns, knives, and arrows could be accessible to people while on fishing vessels. Accordingly, there have been a total of 20 documented gunshot wounds to dolphins in the nGOM (most since 2011; Vail, 2016), and in 2018 a criminal case was opened when a pregnant dolphin was found stranded after being shot in Mississippi (NOAA Fisheries, 2018). Other notable intentional harm cases from the nGOM include a dolphin stabbed in the head with a screwdriver and pods of dolphins targeted with explosives (Alexander-Bloch, 2012; Beverly, 2012). Intentional harm to marine mammals such as bottlenose dolphins is not restricted to the nGOM, these actions occur internationally (Byard et al., 2007; Vail, 2016). Unfortunately, interactions with humans that put marine mammals at risk can also be pervasive through time because mothers teach begging-depredation and vessel following to calves, propagating reliance on human interactions for food and altering the natural behavioral and movement patterns of animals (Cunningham-Smith et al., 2006; Powell et al., 2018; Vollmer & Rosel, 2013). With historical trends of intentional harm towards dolphins continuing to rise, more research is needed to detect and understand relationships between human interactions and marine mammal mortality.

These data contribute to the developing field of wildlife forensics for application by stranding response and management agencies. Signs of intentional harm can be difficult to detect if obvious signs (e.g., attached fishing gear, bullets, noticeable hemorrhage, or other sources of injury) are not grossly observed (Smith-Blackmore & Robinson, 2018). In this study, the X-shaped lesions were not the cause of death, but histological evaluation enabled us to determine that lesions in Case 2 occurred antemortem, allowing us to effectively rule out postmortem changes and focus on alternative sources. These findings further emphasize the need for histological analysis on any suspected human interaction cases to determine the timing of tissue damage and rapid assessment to inform potential criminal cases. Results from our study also suggest that intentional harm may be more commonplace than previously thought, and human interactions have potential for sublethal contributions to health and future injury or mortality. Sharing data across stranding networks will help track these trends of intentional harm to guide management and enforcement in areas of need.

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ORCID

Merri K. Collins https://orcid.org/0000-0003-2323-4216

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