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ARTICLE

Examining the Severity of Roof-Hooking Injuries in Dolphinfish: a Comparison between Computed Tomography and Gross Necropsy

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Abstract
We describe hook trauma to the roof of the mouth in Dolphinfish *Coryphaena hippurus* and compare computed tomography (CT) scanning to gross necropsy (GN) as a technique for diagnosing hooking injury in fish. Forty-two Dolphinfish carcasses spanning a range of hook injuries were collected and CT scanned, and 33 of those carcasses were evaluated using GN. Specimens were hooked either in the roof of the mouth, the eye via the roof or upper jaw, or the jaw (control group). In 75% of roof-hooked individuals, GN revealed nondisplaced to comminuted fractures of the bones of the suspensorium, hematomas in and laceration of the extraocular muscles, and/or damage to the optic nerve. These injuries have the potential to compromise vision and therefore decrease postrelease survival rates of obligate sight-feeding species such as the Dolphinfish. We evaluated the effectiveness of CT scanning to diagnose injury and found that CT could efficiently and accurately identify fractures and some soft-tissue damage, but some injuries found in GN (e.g., optic nerve damage) were not observed on CT scans. Based on our findings, it is likely that mortality is greater in Dolphinfish when hooked in the roof of the mouth than when hooked in the jaw. This study demonstrates a novel technique that was effective at diagnosing hooking injuries associated with the roof of the mouth.

Evaluation of population status requires knowledge of mortality numbers among fish that are caught, whether due to harvest or catch and release (C&R). However, the fate of discarded fish is often unknown (Davis 2002), and disregarding postrelease mortality can lead to uncertainty in stock assessments (Williams 2002; Pollock and Pine 2007). It is important to understand the anatomical effects of hooking and to make use of diagnostic techniques that are best suited for specific species and their respective injuries. This can allow for more informed C&R mortality rate estimates and allow anglers to make more informed decisions when choosing whether to retain their catch. With the increased popularity of C&R, it is valuable to provide information that promotes sustainable angling practices (Brownscombe et al. 2017).

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The recreational fishery in the U.S. South Atlantic region targets Dolphinfish *Coryphaena hippurus* by using hook-and-line gear, and Dolphinfish are most often hooked in the jaw, followed by the roof of the mouth, gill, eye, gut, and body, respectively (C. S. Mikles, personal observation). Dolphinfish are pelagic piscivores that are primarily reliant on sight for foraging (Loew and McFarland 1990). Given their abundance and aggressive feeding behavior, Dolphinfish have supported and continue to support one of the top-ranked recreational fisheries in numbers caught within the U.S. South Atlantic (Rose and Hassler 1969; NOAA 2012). For multiple reasons, including ethical angling, size, and bag limits, Dolphinfish in this region are often released after capture (Carter and Liese 2012). Discard mortality of Dolphinfish has not been estimated for this fishery or for other fisheries directed toward this species throughout its worldwide range.

Many studies that have analyzed C&R mortality rates often incorporate hooking location into these estimates. Hooking location has been established as the most important contributor to postrelease mortality among reviews of C&R studies across species (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005). Hook trauma has been assessed in other recreationally caught fishes but has yet to be characterized in Dolphinfish.

Postrelease mortality for shallow (jaw, roof, and eye) and deep (gut and gills) hooking locations has been studied in several species. Jaw-hooking is generally considered to be a location associated with low mortality, averaging between 0% and 10% (Grover et al. 2002; James et al. 2007; Lyle et al. 2007; Veiga et al. 2011; Campbell et al. 2014). Independent of morphological differences, deep hooking in the gut and gills is often associated with a higher mortality rate than shallow hooking locations (Warner 1976; Domeier et al. 2003; Rudershausen et al. 2014). On the other hand, published estimates of mortality on eye- and roof-hooked fish are more variable, possibly because of the difficulties in observing the degree of injury. Across a number of species, damage to the eye from hooking injuries likely contributes to postrelease mortality due to difficulties with feeding and predator avoidance (Prince et al. 2002; DuBois and Dubielzig 2004; Cooke and Sneddon 2007). The extent of injuries and rate of catch-and-release mortality in Dolphinfish as a result of hooking injury to each of these anatomical sites are unknown.

Many studies that assess C&R mortality rates do not describe roof-hooking or distinguish it from jaw-hooking (Murphy et al. 1995; Taylor et al. 2001; Stachura et al. 2012; Bergmann et al. 2014). This may be due to (1) a perception that roof-hooked fish have mortality rates similar to those of fish hooked in the jaw or (2) the difficulty in observing damage to this location without necropsy (Belle 1997). Mortality for this hooking location ranges from being used as a control (i.e., assuming 0% mortality) in Chinook Salmon *Oncorhynchus tshawytscha* (Grover et al. 2002) to rates as high as 80% in pelagic fishes (Falterman and Graves 2002). This variability is likely due to differences in morphology and feeding behavior across species. Given such variation, it is important to assess injuries to the roof of the mouth on a species-specific basis. The roof of the mouth in Dolphinfish lies in close proximity to the bottom of the eye, which led us to explore different techniques to examine injuries in these tissues.

The objectives of this study were to (1) describe roof-hooking injuries in Dolphinfish and (2) compare computed tomography (CT) scanning to gross necropsy (GN) as a technique for diagnosing hooking injury in fish. Computed tomography scanning has applications in aquatic veterinary medicine to diagnose disease (Garland et al. 2002), but this technique has not been used in published work to investigate the effects of hooking damage in fish or to better understand the impacts of C&R. We hypothesized that hooking location influences the level of injury, and we predicted that roof-hooked fish would have greater injury than jaw-hooked fish.

METHODS

Carcass collection and hook location assignment.— Dolphinfish carcasses were collected during May–July of 2016 and 2017 at the Morehead City, North Carolina, waterfront. Fish were collected opportunistically from a cleaning operation that fillets fish landed by recreational charter boats between 2 and 10 h after they are boated; therefore, the exact gear type, hook size, and landing methods were unknown. While fishing practices differ among boats, the charter fleet typically angles Dolphinfish by trolling with J-hooks and dead natural baits and/or artificial lures or by bailing with circle hooks and dead natural bait (Rudershausen et al. 2012). Additionally, Dolphinfish are gaffed or brought on board without gaffing; after boating, the Dolphinfish are put directly on ice. None of the Dolphinfish retained for CT scanning were gaffed in the head. The FLs of the fish were measured and carcasses were examined for hooking location and external damage. The hooking location was determined through observation of wounds left by hooks or from hooks left in place.

Dolphinfish retained for CT scanning were hooked either in the jaw, eye, or roof of the mouth (Table 1). Fish hooked in the jaw served as controls for CT analysis and injury characterization. Having very minimal injury (see below), jaw-hooked fish also controlled for differences in angling practices and any potential damage inflicted on fish prior to collection.

Computed tomography scanning.— The carcasses collected at the Morehead City waterfront were frozen at

TABLE 1. Number of Dolphinfish collected per dockside-designated hooking location, and the mean and range of FLs for all fish and for fish categorized according to hooking location. Four fish were not measured or included in these averages.

Hooking location	Number of fish	Average FL (mm)	Range of FL (mm)
All	42	679	480–985
Roof of mouth	16	746	504–985
Eye	12	748	505–950
Jaw	14	584	480–880

−20°C. All heads were scanned at the College of Veterinary Medicine, North Carolina State University, using the Siemens SOMATOM Sensation 16 (Siemens Medical Solutions, Malvern, Pennsylvania), with a veterinary small-adult ear setting at a slice thickness of 0.75 mm and a reconstruction increment of 0.4 mm. After CT scanning, heads were stored and thawed at 4°C for subsequent GN (below).

The scanned images were examined with the Horos DICOM medical image viewer (https://www.horosproject.org). The CT scans were first naïvely evaluated by the image analyzer with no knowledge of the hooking location or the extent of injury. The CT scans were re-evaluated a second time after we became more familiar with the images and internal anatomy as well as cross-referencing with dockside hooking location designations. Cross-referencing is an important tool to diagnose conditions and understand the extent of injuries (Cockcroft and Holmes 2003:107–124).

The CT scans were examined in both transverse and coronal sections (Figure 1). Within the CT scan images, bone structure appears white (radio-opaque, mineral opacity), soft tissue and hematoma are gray (soft-tissue opacity), and air-influx is black (gas opacity, radiolucent). Gas is expected in the oral and gill cavities since they are exposed to air after the fish is boated, but air is also introduced through fractures in the bone and can be traceable from the fracture site. Gas as an artifact is sometimes present and can be attributed to air introduced by decapitation or decomposition; control fish served to represent the effects of decapitation and freezing/thawing. Assessing the degree of bilateral symmetry between injured and uninjured sides of the same individual can be used as an internal control since hooking injury occurred only to one side of each individual that we collected.

Roof anatomical evaluations focused on the palate, or suspensorium, which in Dolphinfish is a delicate structure composed of a series of thin bones and cartilages (Figure 2A, B). Specifically, the endopterygoid, ectopterygoid, metapterygoid, palatine, and quadrate form the suspensorium (Hilton 2011). The endopterygoid is the bone most susceptible to fracture caused by hook trauma, due to its thin dorsal shelf that supports and protects the orbital cavity.

We designated three CT injury categories based on our interpretations of the scans: CT 1 represented no visible damage or trauma to the suspensorium or to the orbit (Figure 1A); CT 2 indicated fracture to bone(s) forming the suspensorium, paired with gas influx continuous from the fracture site extending only into the base of the orbit (gas confined to the orbital floor; Figure 1B); and CT 3 represented severe fracture (displaced or comminuted) to bone(s) forming the suspensorium, paired with gas influx continuous from the fracture site extending past the orbital floor dorsally to the level of the optic nerve, extraocular muscles, or the eye (Figure 1C).

Gross necropsy and comparison to computed tomography scans.— We performed GNs to identify the extent of damage caused by hooking and to compare with CT scans. The GNs were necessary because soft-tissue damage in CT scans was evaluated in terms of gas path and volume and adjacent bone fractures rather than observing the injuries in situ. The eye and surrounding structures were examined from a ventral perspective using the following procedure in order to preserve the integrity of the tissues damaged by hooking. First, the opercula and gill arches on both sides of the fish were removed. The lower jaw was removed at the articulation between the maxilla and quadrate and the dentary, exposing the length of the roof of the mouth. The mucosa of the roof was examined for any signs of potential hooking damage (e.g., laceration that penetrates the mucosa), and the outer (ventral) layer was removed, exposing the superficial muscle and the endopterygoid. The muscle and surface of the endopterygoid were examined and then carefully removed, exposing the orbit and the extraocular muscles. The interior surface of the eye and the extraocular muscles were evaluated for damage and then the extraocular muscles were carefully removed. The optic nerve was evaluated for damage or laceration; the conjunctiva was then cut, and the surrounding muscles and mucosa were removed to further evaluate the state of the eye and optic nerve. Finally, the uninjured contralateral orbit was examined as an internal control.

We established three GN injury categories: GN 1 indicated no visible damage or trauma to the suspensorium or to the orbit, with any laceration being minimal and superficial; GN 2 represented visible laceration of the mucosa and fracture to the endopterygoid, with damage to muscle being superficial; and GN 3 represented visible laceration of the mucosa and fracture to the endopterygoid and/or the ectopterygoid, paired with damage to at least one of the extraocular muscles and/or the optic nerve.

The percentage agreement between CT and GN categories was determined to assess the ability to predict GN

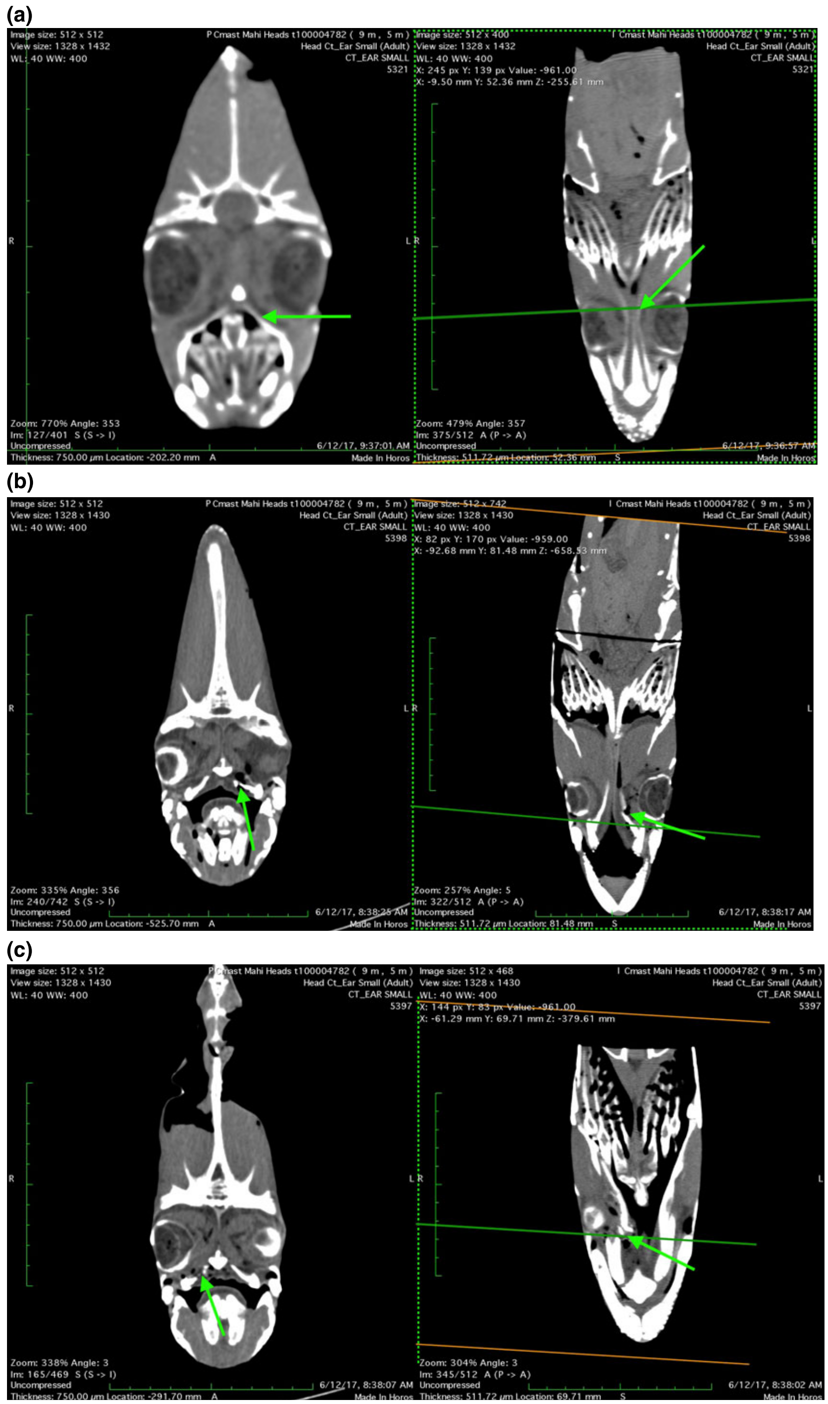

FIGURE 1. Computed tomography (CT) scan diagnoses of Dolphinfish belonging to each category. Each increment of the scale bar on the leftmost side of the image represents 1 cm. **(A)** CT 1 represents no visible damage or trauma to the suspensorium or to the orbit. The individual was hooked in the jaw and served as a control. Gas present in small quantities bilaterally in and behind the eyes is attributed to decapitation and/or decomposition. Arrows indicate the intact bone structure of the endopterygoid in transverse (left) and coronal (right) sections. **(B)** CT 2 represents fracture to bone(s) forming the suspensorium paired with asymmetrical gas influx continuous from the fracture site extending into the base of the orbit (gas is confined to the orbital floor). The individual was hooked in the roof of the mouth. Arrows indicate the fracture site of the endopterygoid (oblique, displaced). Gas is continuous from the oral cavity to the base of the orbital floor. **(C)** CT 3 represents severe fracture (displaced or comminuted) to bone(s) forming the suspensorium, paired with asymmetrical gas influx continuous from the fracture site extending past the orbital floor to the level of the optic nerve, extraocular muscles, or the eye. The individual was hooked in the roof of the mouth. The left arrow indicates gas influx, while the right arrow indicates the fracture site of the endopterygoid (comminuted). Gas is continuous from the oral cavity past the orbital floor, including around the globe.

injuries from CT scans. Additionally, a Kolmogorov–Smirnov (K–S) goodness-of-fit test for discrete ordinal data (Zar 1996) was used to compare the observed CT counts to expected counts (based on GN results) for fish hooked in the roof of the mouth. To provide a qualitative measure of the relative injuries between jaw-, eye-, and roof-hooked Dolphinfish, we calculated a weighted average of injury by hooking location using the number of fish assigned to GN and CT scores. The weighted average was

$$\frac{(n.1 \times 1) + (n.2 \times 2) + (n.3 \times 3)}{\sum n},$$

where $n.x$ is the number of fish in one of the three GN or CT injury categories; and 1, 2, and 3 are the GN or CT injury scores. We performed a Kruskal–Wallis test with Dunn post hoc tests to determine the relationship between hooking location and injury scores assigned through CT and GN (Sokal and Rohlf 1995). Significance was assessed at an α of 0.05. Statistical analyses were conducted in R using the packages "dpylr" and "FSA" (Ogle 2018; R Core Team 2018; Wickham et al. 2018).

RESULTS

Carcass Collection and Hook Location Assignment

Forty-two Dolphinfish carcasses were collected across the three hooking locations (roof of the mouth, eye via the roof or upper jaw, and jaw), and fish ranged in FL from 480 to 985 mm (Table 1). The 14 control fish examined in the laboratory had no injuries to the roof or the eye, confirming the dockside assignment of jaw-hooking.

Computed Tomography Interpretations

The CT scans showed no evidence of fractured bones or gas intrusion in the control fish; however, these injuries were observable on CT scans in 23 of 28 noncontrol fish (Figure 1). Fractures to the bones of the suspensorium could be identified and were categorized as nondisplaced, displaced, or comminuted. Fractures were observed in the endopterygoid more frequently than in any other bone of the suspensorium. Gas artifact could be seen in the eyes and surrounding the orbital cavity in both noncontrol individuals and control fish and could be attributed to the effects of decapitation, decomposition, and freezing/thawing. However, the volume of gas artifact was minimal and distinguishable from gas influx from a fracture site in noncontrol fish, since it appeared random and scattered instead of intruding directly from an epithelial location.

We assigned 14 controls, 5 roof-hooked fish, and 1 eye-hooked fish to CT 1 (Table 2; Figure 1A). There were six roof-hooked and three eye-hooked fish assigned to the CT 2 condition, where scans identified nondisplaced fractures to the bones of the suspensorium and minimal gas intrusion (Table 2; Figure 1B). Scans from fish in CT 3 showed displaced or comminuted fractures to the bones of the suspensorium paired with obvious gas intrusion that was traceable to the level of the orbital floor (Figure 1C); this condition was found in five roof-hooked and eight eye-hooked fish (Table 2). The highest proportion of fish in CT 3 were hooked in the eye, followed by the roof.

Gross Necropsy and Comparison to Computed Tomography Scanning

Gross necropsies were performed on all roof- and eye-hooked fish and on five control fish (total = 33). The remainder of the control fish were examined for external damage but were not dissected. Damage seen by dissection was a result of hook injury; all fish were assigned one of the three GN injury categories (Table 2). All 14 control fish were classified into GN 1; full dissections of all control fish were not necessary to determine their placement in GN 1, as the nine control fish not fully dissected were consistent with the five control fish that were fully dissected. The proportions of fish in GN1, GN2, and GN3 for roof- and eye-hooked fish were similar to the proportions in the CT categories (Table 2). In a few instances, the CT categories overestimated or underestimated the degree of damage as determined by GN but had a total percent agreement of 80.9% with GN. Discrepancies mostly occurred between categories 2 and 3; the CT interpretation underestimated the damage in five cases and overestimated it in three cases. For roof-hooked fish, there was no statistical difference in injury score assignment between the CT and GN (K–S test: $d_{max} = 2$, $P > 0.50$).

For Dolphinfish in GN 1 ($n = 19$), all damage was superficial. Lacerations to the mucosa in the roof of the mouth were observed, but no fracture was observed, and no damage occurred to the superficial muscle. The CT assessment scored 1 and the GN scored 2 for only one individual, which had a chip fracture in the endopterygoid along with slight damage to the surrounding superficial muscle.

For fish in GN 2 ($n = 9$), fractures of varying types and severities to the endopterygoid were observed, but soft-tissue damage did not extend past the superficial muscle, which was often bruised or torn. Of the nine fish that were scored as CT 2, five were also scored as GN 2.

For Dolphinfish in GN 3 ($n = 14$), fractures of varying types and severities occurred to the endopterygoid and ectopterygoid. The superficial muscle was damaged, and damage occurred to the extraocular muscles and/or to the optic nerve. Hematoma was often present in the orbital floor. One roof-hooked fish and three eye-hooked fish sustained injuries to the optic nerve. Of the 13 fish scored as CT 3, 10 were also scored as GN 3.

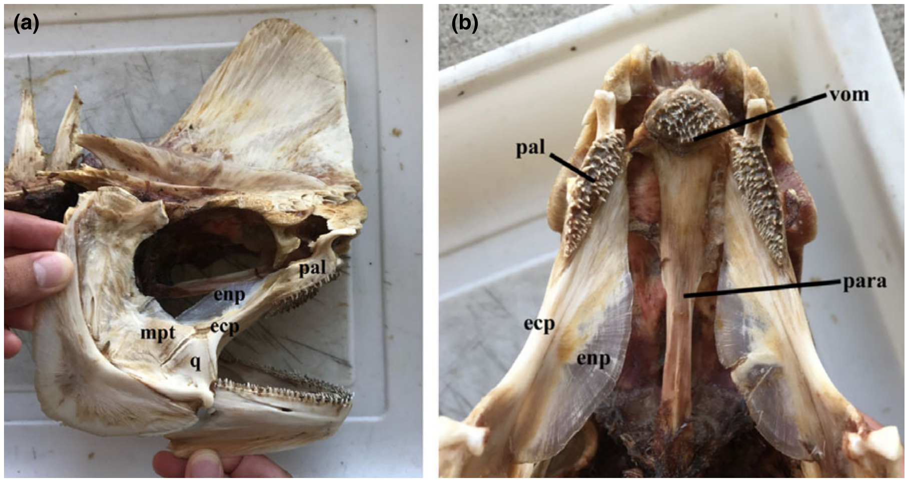

FIGURE 2. Suspensorium of a Dolphinfish in **(A)** lateral view and **(B)** ventral view (ecp = ectopterygoid; enp = endopterygoid; mpt = metapterygoid; pal = palatine; para = parasphenoid; q = quadrate; vom = vomer).

TABLE 2. Computed tomography (CT) and gross necropsy (GN) categorization of all Dolphinfish based on dockside-designated hooking locations.

	Hooking location			
Category	Roof (n = 16)	Eye (n = 12)	Jaw (n = 14)	Total (n = 42)
CT 1	5	1	14	20
CT 2	6	3	0	9
CT 3	5	8	0	13
GN 1	4	1	14	19
GN 2	5	4	0	9
GN 3	7	7	0	14

Of the 16 fish hooked in the roof, 4 were assigned to GN 1; 5 were classified as GN 2; and 7 were assigned to GN 3. Of the 12 fish that were hooked in the eye (globe or fornix) via the roof or upper jaw, 1 was placed in GN 1; 4 were assigned to GN 2; and 7 were placed in GN 3. All control fish were placed in GN 1. Twelve of 16 (75%) roof-hooked fish sustained a combination of fractures to the suspensorium, laceration of extraocular muscles, and/or optic nerve damage. Assessment by CT never diagnosed damage where none was detected by GN. There was no identifiably consistent manner in which the endopterygoid was fractured, except that the thinnest parts of the bone were most susceptible to damage.

The weighted average injury scores for jaw-, roof-, and eye-hooked Dolphinfish were 1.0, 2.2, and 2.5, respectively, for GN and were 1.0, 2.0, and 2.6 for CT. The results of the Kruskal–Wallis test showed differences in the severity of hooking injuries among jaw-, roof-, and eye-hooked fish for CT (χ^2 = 22.6, P < 0.001) and GN (χ^2 = 22.3, P < 0.001) techniques. Post hoc analyses for each categorization revealed differences between jaw and roof (P < 0.002) and jaw and eye (P < 0.001) for both GN and CT techniques; however, there were no differences in injury scores between roof and eye (P > 0.05) for either technique. Thus, roof-hooked Dolphinfish had injury levels that were closer to those of eye-hooked individuals than to those of jaw-hooked fish.

DISCUSSION

The effects of roof-hooking in contributing to C&R mortality have seldom been studied compared to the total number of C&R mortality estimates. Our prediction that Dolphinfish hooked in the roof of the mouth would sustain more severe injuries than jaw-hooked fish was supported by CT and GN findings. Although our sample of 16 roof-hooked fish was modest, the extent and variability in injury were extensive.

There was a high percentage (75%) of roof-hooked Dolphinfish with damage to the bones of the suspensorium, extraocular muscles, and/or optic nerve. The same injuries were observed 92% of the time in eye-hooked fish. The CT scans and GN results had similar findings when the bones of the suspensorium were fractured; however, there was ambiguity in determining the extent of soft-tissue damage with CT. The CT scans show bone structure more accurately, so differences in fracture severity were easily discernable to categorize fish in either CT 2 or CT 3. Tracing the path of gas influx provided some indication of the extent of damage present, but results from GNs were more definitive. For roof- and eye-hooked fish, internal damage to the musculature, nerve pathways, and orbit can vary in severity and is not necessarily correlated with the severity of fracture. The GNs served to validate the diagnoses from the scans and also provided more specific information on soft-tissue damage. The diagnoses from the CT agreed with the GN around 80% of the time. We have demonstrated the use of CT for comparing the severity of hooking injuries across hooking locations that are difficult to observe and have not been previously studied in Dolphinfish.

The endopterygoid and superficial muscle provide a thin layer of protection between the oral and orbital cavities and are not suited to withstand hook damage. Our understanding of these injuries provides insight into the potential for postrelease survival. The injuries we describe can result in severe eye damage and potentially impair vision. For example, damage to the lens or the sclera, intraocular hemorrhage, and enucleation were designated as injuries most likely to result in long-term visual impairment of stream trout (DuBois and Dubielzig 2004). Fish hooked in eye-associated tissues will likely suffer a degree of vision loss, which has been associated with higher mortality (Warner 1976; Pauley and Thomas 1993). If selectively harvesting, anglers may consider choosing to keep individuals with greater hooking damage (Brownscombe et al. 2017). Given the importance of sight-feeding for Dolphinfish, we recommend retaining individuals of legal size with eye- or roof-hooking over fish hooked in the jaw. Additionally, trolling with circle hooks would reduce the amount of deep (e.g., eye and roof) hooking (Rudershausen et al. 2012).

Dolphinfish that were hooked in the roof of the mouth sustained higher degrees of damage than jaw-hooked fish. Thus, hooking in the roof of the mouth would likely result in higher mortality than jaw-hooking based on the injuries that we observed. Fractures and muscle damage often cause blood loss, and these hook injuries can create pathways through which seawater and pathogens may be introduced to vital areas. Depending on the severity and location of hooking damage, the presence of bleeding is often linked to postrelease mortality, as it is dependent on the perfusion of vasculature and critical organs (Arlinghaus et al. 2007). Numerous studies have found that bleeding and hooking location are the most important factors when assessing mortality of angler-caught fish (Nuhfer and Alexander 1992; Meka 2004; Weltersbach and Strehlow 2013; Gargan et al. 2014). We did not observe bleeding immediately after angling, although hematoma was often present in the orbital cavity in roof-hooked fish with medium (GN 2) or high (GN 3) degrees of damage. The degree of physical trauma can be a good predictor of mortality (Domeier et al. 2003; Skomal 2007), but we recommend a more quantitative estimate of C&R mortality by hooking location in Dolphinfish via the use of experimental caging (Grover et al. 2002; Gutowsky et al. 2015), large-scale mark–recapture studies (Pine et al. 2003; Rudershausen et al. 2014), telemetry (Capizzano et al. 2016), or accelerometer loggers (Brownscombe et al. 2013; Lennox et al. 2018).

Of the studies that have examined injuries and mortality for roof-hooked fish, the results have been mixed and are likely species specific. Roof-hooking has been observed and described in other pelagic fishes (Falterman and Graves 2002; Prince et al. 2002, 2007). Falterman and Graves (2002) assessed hooking mortality among pelagic fishes and determined a discard mortality rate of 80% for fish hooked in the roof of the mouth; however, the sample size was small ($n = 5$), and the mortality rate determined for jaw-hooked fish (corner and lower jaw) was also notably high (48.9%). The injuries to roof-hooked Dolphinfish were very similar to those described by Prince et al. (2002, 2007) for roof-hooked Atlantic Sailfish *Istiophorus platypterus*. Hooking in the roof of the mouth resulted in lacerations to the rear palate and hemorrhaging of the eye in Sailfish (Prince et al. 2007). Those authors classified hooking in the roof to be an undesirable location that may lead to postrelease mortality due to latent injuries to the eye. The resemblance of roof-hooking injuries in our study to the findings of Prince et al. (2002, 2007) is likely a result of similarities in anatomy, as both Dolphinfish and Sailfish have an insubstantial palate. Among more distantly related fishes inhabiting different environments, results for roof-hooking were increasingly varied. For example, Cutthroat Trout *O. clarkii* individuals hooked in the jaw had an estimated mortality rate of 6%, while those hooked in the roof of the mouth showed a mortality of 29% (Pauley and Thomas 1993). In Pumpkinseeds *Lepomis gibbosus* with molariform teeth, roof-hooking was insignificant in discard mortality estimates (Cooke et al. 2003); in Chinook Salmon, the roof of the mouth was designated as a location with minimal injury and treated as a control for mortality estimates (Grover et al. 2002). We recommend future research on hook injuries for fishes known to have mouth and eye morphologies similar to those of Dolphinfish and Sailfish.

We observed severe injuries to a peripheral hooking location that outwardly do not appear to result in severe damage. This has also been the case for roof injuries to Bluefin Tuna *Thunnus thynnus*, in which the same injury could only be characterized by performing GNs (Belle 1997). In sharks, hooking damage to the basihyal was suggested to result in high mortality, which was unexpected (Danylchuk et al. 2014). Serious injuries from hooking are likely found in other fishes, and this is an area worthy of future research. Increased use of these diagnostic tools for specific species and fisheries will aid in the understanding of hooking injuries to different locations and allow anglers to make more informed decisions when practicing C&R.

Our research is unique in that it used detailed necropsy and medical imaging to reveal cryptic hooking injuries. Computed tomography scanning may be a tool that C&R researchers choose to use in future studies given the agreement between approaches and the time savings of CT scanning. Additionally, CT scanning could be used as a first approach to identify severely injured fish for GNs. The GNs were more insightful but required considerably more time than scanning. However, GN validated the CT interpretation and revealed the mechanism and character of the respective injuries.

Although this study was specific to Dolphinfish, we demonstrate a novel application of CT techniques that are becoming more accessible with improved technology, free imaging software, and scientific interest in scanning fish. In tandem with detailed necropsies, CT offers an enhanced technique to characterize injuries that provides insight into the potential risk for postrelease mortality. The application of similar methods to other fish species with similar anatomies could expand our current understanding of the various injuries caused by hooking.

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