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Evaluating prevalence of external injuries on nesting loggerhead sea turtles *Caretta caretta* in southeastern Florida, USA

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ABSTRACT: Sea turtles face both anthropogenic and natural threats including boat strikes, fisheries, pollution, and predator attacks. Injuries from anthropogenic sources are more common than naturally caused injuries. The goal of this study was to determine prevalence and cause (e.g. boat strike, entanglement, hook, shark bite) of injuries on nesting loggerhead sea turtles *Caretta caretta* on Juno and Jupiter beaches, Florida, USA. During the 2019 and 2020 nesting seasons, 450 loggerhead females were examined for external injuries. Injuries were categorized by anatomic location, condition, and cause. We found that 24% of loggerheads had at least 1 injury. Of the 111 injuries found on 107 nesting females, 88% were healed, 9% were partially healed with some scarred tissue, and 3% were fresh injuries. Most injuries (55%) were lateral injuries on the carapace or appendages. We were able to attribute 60 injuries to a specific cause. Boat strikes accounted for 75% of the 60 injuries, shark bites accounted for 15%, fishing hooks accounted for 7%, and entanglements accounted for the remaining 3%. This study provides new insight into the prevalence of anthropogenic injuries relative to natural injuries in loggerhead sea turtles nesting in the most densely nested beach in the Western Hemisphere and can be used to improve conservation management plans through implementation of fishing and/or boating restrictions in the nesting and foraging areas most commonly frequented by sea turtles.

KEY WORDS: Anthropogenic injuries · Boat strike · Shark bite · Hook · Entanglement · Marine turtle · Palm Beach County

1. INTRODUCTION

Sea turtles are exposed to numerous anthropogenic threats including fisheries bycatch, harvest of eggs and live turtles, coastal development, pollution and plastic ingestion, climate change, and boat interactions (Wallace et al. 2011). Anthropogenic threats are thought to account for 2 to 3 times more sea turtle deaths than those resulting from natural causes; however, some of these threats remain largely unquantified (Casale et al. 2010, Bolten et al. 2011, Foley et al. 2015). Understanding the prevalence of non-lethal anthropogenic and natural injuries on wildlife, especially large migratory spe-

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cies like sea turtles, is important for improving conservation management plans (Hazel & Gyuris 2006).

In Florida, USA, an estimated 3.7% of sea turtle strandings are due to hook and line interactions or some other form of entanglement (only 0.5% from non-fishing gear) (Foley et al. 2015). Sea turtle strandings associated with boat strikes increased in Florida from 10 to 30% between 1985 and 2005 (Singel et al. 2008). Approximately 43% of sea turtle strandings are related to boat injuries in Palm Beach County, Florida, where there is greater boat traffic than in other Florida counties (Singel et al. 2008, Foley et al. 2015). Lastly, 4.3% of loggerhead *Caretta caretta* strandings in Florida are due to shark bite injuries (Foley et al. 2015). Stranding data may underestimate fishing gear-related turtle mortality due to the absence of scars on dead stranded turtles and the inability to account for scarring when carcasses are in advanced stages of decomposition (Peckham et al. 2008, Mancini & Koch 2009). Interactions with all threats may be underestimated using stranding data, as previous injuries heal and fade. In addition to injuries being undetectable, scientists must be conservative when determining the cause of death of stranded turtles, which leads to even further underestimations of each injury type (Foley et al. 2015). It is critical to understand how turtles are interacting with these threats even if the interaction does not lead to mortality.

Entanglement and hook wounds result from direct interactions with fisheries or fishing lines and nets that have been lost or discarded (i.e. ghost gear; Wallace et al. 2010b, Hamelin et al. 2017, Duncan et al. 2017). Hook wounds often occur due to foraging behavior around pelagic longlines or piers, whereby sea turtles attempt to consume bait on the hook or become entangled in the fishing line (Lewison et al. 2004, Watson et al. 2005). This can lead to ingestion of the hook or external hook-related injuries (Watson et al. 2005). Turtles struggling in the fishing line can lead to further entanglement (Hamelin et al. 2017). Entanglement is one of the leading causes of mortality in marine megafauna, including sea turtles (Knowlton & Kraus 2001, Robbins & Mattila 2004, Chaloupka et al. 2008, Knowlton et al. 2012).

When turtles directly interact with fisheries, they usually end up as bycatch, and as such, they either drown, are released with minimal to moderate trauma or with severe injuries that later result in death (Knowlton & Kraus 2001, Lewison et al. 2004, Peckham et al. 2008, Murray 2015). Direct boat collisions are a major cause of injury for manatees, cetaceans, and marine and freshwater turtles, resulting in propeller injuries or blunt force trauma (Laist & Shaw 2006, Vanderlaan & Taggart 2007, Heinrich et al. 2012, Dwyer et al. 2014, Foley et al. 2015). Even if death is not immediate, these interactions can affect health (e.g. infection, muscle necrosis) and biology (e.g. feeding, locomotion, reproduction) of turtles, which may ultimately result in mortality or have population-level effects by reducing reproductive success (Moberg 1985, Innis et al. 2010, Hamelin et al. 2017).

Natural threats, including disease, cold stuns, harmful algal blooms, and predator attacks, also impact sea turtle health and survival (Bolten et al. 2011). Because predator–prey relationships are difficult to observe in the ocean, there is limited information on the impacts that predation has on sea turtle populations (Heithaus et al. 2002). Loggerheads often have a greater prevalence of shark bite injuries in comparison to green turtles *Chelonia mydas*, as they swim at slower speeds and have less maneuverability (Heithaus et al. 2002). Compared to predator attacks, anthropogenic injuries in northwestern Atlantic leatherback sea turtles *Dermochelys coriacea* are twice as common (Archibald & James 2018).

Loggerheads nest at greater numbers than any other sea turtle species in Florida (Florida Fish and Wildlife Conservation Commission [FWC] 2021) and are considered threatened under the US Endangered Species Act (Conant et al. 2009). Based on Florida's nest numbers, the loggerhead population appears to be stable (Ceriani et al. 2019); therefore, it is important to identify and quantify all threats to gather an accurate picture of what is primarily impacting local populations. Stranding data have been influential in understanding what threats are contributing most to sea turtle stranding and mortality (Kopsida et al. 2002, Hazel & Gyuris 2006, Singel et al. 2008, Casale et al. 2010, Bolten et al. 2011, Denkinger et al. 2013), but part of the story is missing: How many turtles are injured and never strand? To better understand threats to live sea turtles that have never stranded, the objective of this study was to determine prevalence and cause of fresh and healed external injuries on nesting loggerhead sea turtles on Juno and Jupiter beaches, Florida.

2. MATERIALS AND METHODS

2.1. Study site

Ten regional management units have been identified worldwide for loggerhead sea turtles (Wallace et

al. 2010a), with the northwest Atlantic population considered the largest, consisting of 42% of the world's total nesting activity for this species (Casale & Tucker 2017, Ceriani & Meylan 2017). Subsequently, ~90% of loggerhead sea turtle nesting activity from the northwest Atlantic subpopulation occurs in Florida (Ceriani et al. 2017). Palm Beach County hosts the highest number of loggerhead nests annually in Florida, with 28790 nests (~27% of statewide total) laid in 2019 and 29465 nests (~28% of statewide total) laid in 2020 (FWC 2021). On average (±SD) from 2011 to 2020, 7342 ± 1463 loggerhead nests (range 5153–9960 nests) were laid each year on Juno and Jupiter beaches (Loggerhead Marinelife Center [LMC] unpubl. data), making these areas home to the highest densities (in nests per km) of loggerhead nesting beaches in the Western Hemisphere (Ceriani & Meylan 2017, Nelson Sella & Fuentes 2019). These nest numbers equate to ~859–2490 individual females (using an estimated clutch frequency of 4–6 nests per season; Tucker 2010). The study sites, Juno and Jupiter beaches (12.3 km; 26.836° N, 80.041° W to 26.943° N, 80.072° W), are located in northern Palm Beach County adjacent to LMC (Juno Beach, Florida). Juno and Jupiter beaches have been monitored annually using standardized sea turtle nesting survey protocols since 1989 (FWC 2016). Therefore, this important nesting population is assumed to serve as a good representation of the southeastern Florida loggerhead recovery unit (Shamblin et al. 2011).

2.2. Data collection

Data were collected during the loggerhead nesting season from 17 Jun to 13 Jul 2019 and 16 Apr to 8 Aug 2020. Nesting beaches were patrolled nightly from 21:00 to 03:00 h using all-terrain vehicles. Turtles were approached either (1) during their nesting fixed action pattern (during oviposition after ~50 eggs had been laid), when they are generally unresponsive to stimuli, or (2) during the camouflaging stage (i.e. post oviposition). No turtles were handled, tagged, or photographed before eggs were laid. A complete physical exam was conducted to visually assess each turtle for the presence of external injuries (Deem & Harris 2017, Page-Karjian & Perrault 2021).

Standard curved carapace length (CCL) and curved carapace width (CCW; after Wyneken 2001) were recorded from each encountered loggerhead. If an injury was present, the following information was also recorded: cause of injury (if known; e.g. boat strike, predator attack, hook, entanglement), location (e.g. head, extremity, lateral carapace, medial carapace; Fig. 1), and condition (e.g. fresh, partially healed, healed). If the injury was a series of parallel strikes, blunt force trauma, or a clean cut, it was identified as a boat strike injury (Work et al. 2010). Predator attacks were identified if the injury was crescent shaped and/or included parallel rake marks (Heithaus et al. 2002). Hook injuries were identified by the presence of puncture wounds, with raised scar tissue where the puncture occurred (Watson et al. 2005), or when a small piece of the maxilla was missing. Loggerhead sea turtles have relatively accurate target biting, which results in greater hooking in the mouth, throat, and stomach (Epperly et al. 2012, Warraich et al. 2020); therefore small pieces of the maxilla that were missing were categorized as hook injuries. Injuries were categorized as entanglement if lacerations encircled the neck or appendage or if gear (which was removed from the animal during oviposition) was still present on the turtle (Innis et al. 2010, Archibald & James 2018). Fresh injuries were defined as those with open wounds with blood present and the absence of scarring tissue. Partially healed injuries were identified by the presence of scarring tissue with pink and/or yellow skin where the wound was beginning to close. Lastly, healed injuries were identified by the absence of scarring tissue and a closed wound; scars are still present on some fully healed injuries.

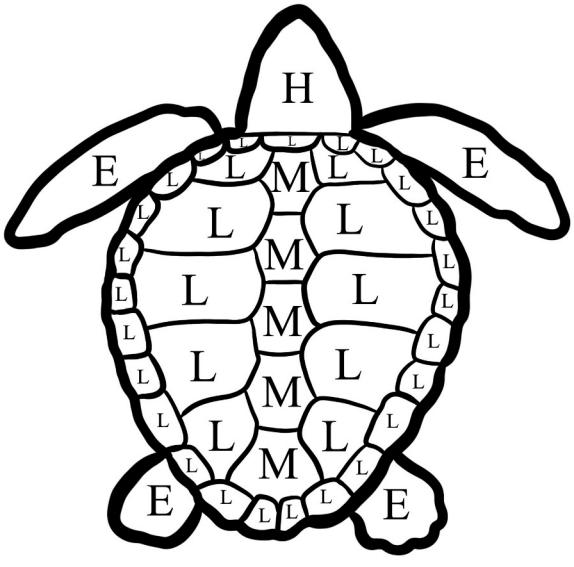

Fig. 1. Classification of injury location on nesting loggerhead sea turtles *Caretta caretta*. H: head; E: extremities; L: lateral carapace; M: medial carapace

Untagged turtles were tagged with Inconel flipper (National Band and Tag Company) and MiniHPT8 pre-loaded sterile syringe passive integrated transponder tags (Biomark®). All handling and tagging of sea turtles was conducted by personnel authorized on the relevant FWC marine turtle permit (MTP no. 205) and followed FWC guidelines highlighted in their Marine Turtle Conservation Handbook (FWC 2016). Photographs were taken of the turtles and their injuries using red external light-emitting diode headlamps. Images provided a way to document and confirm cause of injury. The entire carapace and head were included in each image. Photos were taken of the dorsal surface of the turtle at a 90° angle. If the injury was from an entanglement or hook, photographs from different perspectives (e.g. lateral, anterior) were taken to better categorize the injury. Photographs and injuries were reviewed and classified by 2 experienced veterinarians.

2.3. Statistical analyses

To determine if there was a greater prevalence of anthropogenic injuries (e.g. boat strike, hook, entanglement) compared to non-anthropogenic injuries (e.g. predator attack) present on nesting loggerhead sea turtles, Fisher's exact tests with post hoc comparisons and Bonferroni adjusted alpha levels were conducted. Statistical significance was set to $p \leq 0.05$. All statistical tests were performed using R 3.5.3 (R Core Team 2019), while ggplot2 version 3.3.0 was used to produce figures (Wickham 2016).

3. RESULTS

Nesting loggerhead sea turtles were assessed during the 2019 (n = 300) and 2020 (n = 150) nesting seasons. Our sample size accounted for ~14 to 21% of the nesting population in 2019 and 7 to 11% of the nesting population in 2020 (8724 and 8618 loggerhead nests were laid on Juno and Jupiter beaches in 2019 and 2020, respectively, with an estimated 1454–2200 females in 2019 and 1436–2155 females in 2020 based on a clutch frequency of 4–6 nests per season; Tucker 2010). Average CCL and CCW for nesting loggerheads were 95.8 ± 6.7 and 88.4 ± 6.1 cm, respectively. Of the turtles assessed, 24% (n = 107 of 450) had 1 or more external injuries. Four turtles with multiple causes of injury had the following combinations: entanglement and boat strike, hook and boat strike, hook and unknown, and boat strike and unknown. Of the 111 identified injuries, 46% were of unknown cause (Fig. 2A,B). Of the 60 injuries with identifiable cause, 75% were boat strikes (Fig. 2C,D), 15% were shark bites (Fig. 2G,H), 7% were hook injuries (Fig. 2I,J), and 3% were entanglements (Fig. 2E,F). In this study, unknown injuries primarily consisted of damage to the extremities and/or the lateral carapace (n = 38 of 51; 75%), which were usually smaller injuries and more difficult to classify. Prevalence of unknown injuries was not statistically different from anthropogenic injuries, but both were significantly greater than injuries from natural causes ($p < 0.001$). Therefore, unknown injuries were excluded from statistical analysis when testing for significant differences among different injury causes. Turtles were more likely to have boat strike injuries compared to shark, hook, or entanglement injuries ($p < 0.001$; Fig. 3).

Of the injuries on 107 nesting females, 88% were healed, 9% were partially healed, and 3% were fresh injuries with no scarring tissue present. Most injuries (55%) were lateral injuries on the extremities or carapace (Table 1). Six nesting females had head injuries (Table 1). Head injuries were minor, caused by a hook (n = 3 of 6) or unknown cause (n = 3 of 6).

4. DISCUSSION

In Florida, boat strikes are the most common cause of death in stranded loggerhead sea turtles, accounting for one-third of all loggerhead strandings from 1980 to 2014 (Foley et al. 2015, 2019); therefore, it was expected that nesting loggerhead turtles on Juno and Jupiter beaches would have a higher prevalence of anthropogenic injuries compared to non-anthropogenic injuries. Approximately 85% (n = 51 of 60) of injuries with an identifiable cause on nesting loggerheads included in this study were anthropogenic (e.g. boat, hook, entanglement), with the most prevalent injuries due to boat strikes. It is unknown where all injuries found in this study occurred geographically, but 3 turtles had fresh injuries indicating they were likely sustained during nesting season. One of these fresh injuries was of unknown origin, while the other 2 were boat strikes.

In total, 10% (n = 45 of 450) of loggerheads on Juno and Jupiter beaches had boat-related injuries, accounting for ~75% of all injuries recorded with a known cause. If the data from our sample population were expanded to the entire female loggerhead population on Juno and Jupiter beaches for 2019 and 2020 (~2890–4336 female loggerheads), then we esti-

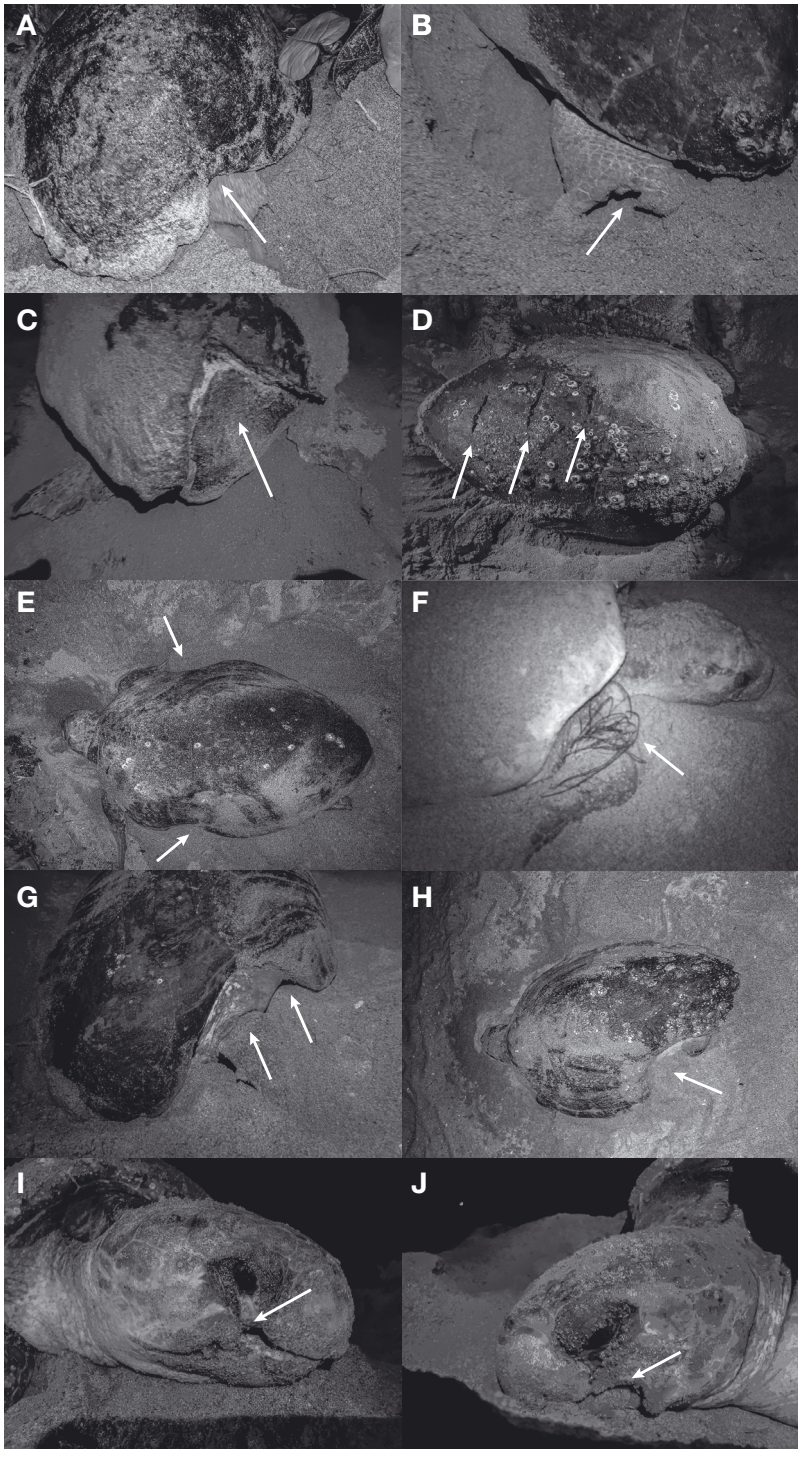

Fig. 2. Examples of external injuries identified on nesting loggerhead sea turtles *Caretta caretta* from Juno and Jupiter beaches (Florida, USA) during the 2019 and 2020 nesting seasons. (A) Small injury of unknown cause on the right lateral carapace; (B) injury of unknown cause on the left hind limb; (C,D) boat strike injuries; (E) concave injuries on the lateral carapace, likely due to an entanglement that occurred earlier in the turtle's life that constricted the carapace during growth; (F) fishing line entangled around the right front flipper; (G,H) crescent-shaped amputation of the lateral carapace, likely from a shark interaction; (I,J) pieces of maxilla missing, identified as hook injuries

mate that ~289 to 437 turtles could have boat injuries. With boat strikes affecting 10% of the nesting population, it is possible that sublethal effects would impact population recovery. Boat strike injuries can prevent successful nesting, as several loggerheads (and green turtles) were observed during the 2020 and 2021 nesting seasons with partial paralysis of their hind limbs due to boat strikes (LMC, unpubl. data). Additionally, female diamondback terrapins *Malaclemys terrapin* with missing hind limbs may have difficulty in successfully digging a nest (Cecala et al. 2009) and male wood turtles *Glyptemys insculpta* with at least 1 missing limb are often unable to mate (Burger & Garber 1995). Loggerheads will still attempt to nest if injured, as observed in the present study; however, an evaluation of clutch size, hatching success, clutch frequency, and remigration intervals of injured sea turtles has not yet been conducted. Trade-offs between wound healing and reproduction are influenced by life-history strategies (Stearns 1992, Archie et al. 2014). For species with a long lifespan, such as loggerheads, it may be more reproductively advantageous to put more effort toward wound healing instead of reproduction (Zuk & Stoehr 2002). Therefore, even if sea turtles survive the initial boat strike, subsequent problems may result that affect their reproductive ability and/or overall health.

Generally, sea turtles are not able to avoid being hit by boats at speeds higher than 4 km h^{-1} (2.5 miles h^{-1}), with most boat traffic greatly exceeding this speed (Hazel et al. 2007). Speed also plays a role in the degree of damage done to a turtle in a collision, with faster speeds inflicting more damage (Work et al. 2010). Boating restrictions, both mandatory and voluntary, have been successful in protecting marine mammal species (e.g. North Atlantic right whale *Eubalaena glacialis*) in the western Atlantic

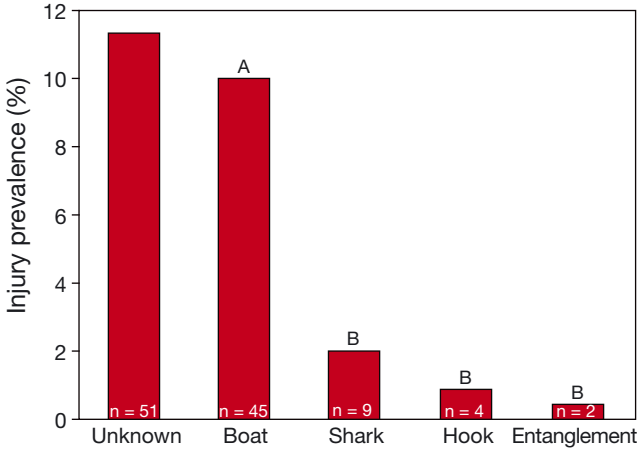

Fig. 3. Injury prevalence data for 450 nesting loggerhead sea turtles *Caretta caretta* from Juno and Jupiter beaches (Florida, USA) during the 2019 and 2020 nesting seasons. n: number of turtles with each injury cause. Different letters above columns indicate significant differences among causes of injury, excluding unknown injuries (Fisher's exact test, $p < 0.001$)

Table 1. Number and percentage of nesting female loggerhead sea turtles *Caretta caretta* collected on Juno and Jupiter beaches (Florida, USA) displaying injuries on different anatomical locations

Injury location	Count	Percentage (%)
Lateral carapace	31	29
Medial and lateral carapace	30	28
Extremity	21	20
Medial and lateral carapace and extremity	7	7
Lateral carapace and extremity	7	7
Medial carapace	4	4
Head	2	2
Head and extremity	2	2
Head and lateral carapace	1	1
Head and medial and lateral carapace	1	1
Medial carapace and extremity	1	1

Ocean (Laist & Shaw 2006, Vanderlaan & Taggart 2009, Silber & Bettridge 2012, Martin et al. 2016). Surveys completed by boaters show that they are generally supportive of boat speed restriction zones, especially if there is increased outreach and education, restrictions are voluntary or seasonal, and/or the zones expand upon already existing zones (Fuentes et al. 2021). The loggerhead recovery plan includes boat interactions as a major threat to the northwestern Atlantic loggerhead population (NMFS & USFWS 2008); however, the 2019 progress assessment of the recovery plan states that boat strikes have not yet been addressed in terms of loggerhead population recovery (Bolten et al. 2019), as there are currently no boating regulations in Florida state waters to protect sea turtles (FWC 2019). The impact of boats on the nesting loggerhead population (~10% with boat strike injuries) on Juno and Jupiter beaches, Florida, warrants further action to remediate the issue.

Our results were similar to injury data collected from leatherback sea turtles *Dermochelys coriacea* in the northwestern Atlantic Ocean, where anthropogenic injuries were significantly more abundant than predatory injuries; however, entanglement and hook injuries were more common in leatherbacks compared to boat strike injuries (Archibald & James 2018). Leatherback turtles in the northwestern Atlantic Ocean likely show dissimilarities in cause of injury and prevalence due to differences in behavior, diet, migratory patterns, and nesting and foraging locations. Leatherbacks are particularly vulnerable to entanglement in northern Atlantic coastal and shelf waters, where fishery interactions are a major threat (James et al. 2005). Loggerheads, on the other hand, return as subadults to nearshore foraging habitats, which have greater recreational boat traffic, thus increasing their chances of interactions with boats (Thomson et al. 2012, Ceriani et al. 2017). The present results pertaining to cause of injury and prevalence are consistent with results from stranding data, which show that boat injuries are the most common injury found in loggerheads (Foley et al. 2015). Data collected on live turtles do not account for those individuals that do not survive these interactions. Continued research on injuries present on live turtles, in combination with stranding data, can provide more robust information to support conservation efforts. Our current nesting loggerhead injury data, along with Florida stranding data, indicate that anthropogenic threats represent a greater risk to nesting loggerheads on Juno and Jupiter beaches, Florida, than predator attacks.

Loggerheads are more vulnerable to boat injuries when migrating and during nesting season, when they are more likely to be found near the surface compared to when foraging (Foley et al. 2019). There are major foraging hotspots in Florida, the Caribbean, and along the east coast of the USA (Ceriani et al. 2017). Commercial lobster, conch, and snapper fisheries operate on the continental shelves of the Bahamas (Moultrie et al. 2016), which could increase the interactions of loggerheads with fishing gear, but our study found very few entanglement and hook injuries. Given the lower prevalence of entanglement and hook injuries found in this study, the boat

injuries found on nesting loggerheads on Juno and Jupiter beaches are more likely due to recreational boating sources rather than commercial fishing boats. However, the prevalence of entanglement injuries is underestimated due to difficulty in detection, since fishery interactions do not always result in scarring (Peckham et al. 2008, Archibald & James 2018). Most of the injuries (94 of 107; 88%) identified in nesting loggerheads in this study were healed, and it is likely that some healed injuries, especially on soft tissue, went undetected. Sea turtle wounds can take months to years to enter the final phase of healing (Mettee & Norton 2017). Since scarring is not always present after a fishery interaction, and most injuries evaluated in this study were healed and evaluated under field conditions, it is possible that entanglement and other injuries were underestimated. Another possible source of injury underestimation is that the plastron on nesting loggerheads could not be observed, limiting the ability to detect injuries located on the ventral side of the turtle.

Injuries of unknown source were typically smaller and present on the lateral carapace. Loggerhead hatchlings held together in captivity show aggression towards one another and often bite at each other's extremities, posterior carapace, and neck (Higgins 2003). It is also possible that small fish and/or other predators may bite at turtle extremities, resulting in small injuries that eventually heal (Fretey 1981, Innis et al. 2010). Thus, small unidentifiable injuries on the front flippers, rear hind limbs, and lateral carapace of loggerheads in our study were likely the result of partial predation. Other larger injuries categorized in this study as unknown could have been caused by boats, predation, or fisheries interactions. Therefore, some injury categories, including natural causes, are likely underestimated, since 46% of injuries on nesting loggerheads were unidentifiable.

Shark bite injuries are less prevalent in older life-stage classes, whereby the threat of predation decreases as sea turtles grow (Heithaus et al. 2008). Hatchlings and juveniles are more often affected by predators including ghost crabs, raccoons, ants, tarpon, catfish, and sharks compared to adult turtles, which have sharks as their most common predator (Heithaus 2013). Sharks more often target juvenile turtles than adults, and the juveniles that are attacked do not always survive to adulthood to display these injuries (Limpus & Limpus 2003). This may explain why so few adult turtles from our study had shark bite injuries (n = 9 of 450; 2%). Shark predation may have a greater impact on loggerhead populations than indicated by the present study. Since loggerheads in the northwestern Atlantic Ocean do not exhibit shark risk avoidance behaviors (Hammerschlag et al. 2015), the lower prevalence of shark injuries is likely due to larger size rather than behavioral changes.

It is unknown why some wounded sea turtles never strand, but factors including severity, location, size, and body condition during injury are likely reasons. Over half (~55%) of the injuries recorded in this study were present only on the lateral carapace and/or extremity. Lateral carapace and extremity injuries avoid the spinal column and major organs (Wyneken 2001), which may explain why turtles survived these interactions. Six nesting loggerheads were found with head injuries, all of which were either hook (n = 3 of 6) or unknown (n = 3 of 6) injuries that caused minor damage. Since no large head injuries were documented on nesting loggerheads, it is likely that survival in turtles with moderate to severe head injuries is low (Ataman 2020) and that these were thus not as likely to be sampled in our study.

Turtles may acquire multiple injuries from different causes over time. For example, 8 green turtles of various life-stage classes in Malaysia each had new boat strike injuries during the 7 yr duration of the study, with 1 adult turtle experiencing multiple boat strikes in just 3 yr (Phu & Palaniappan 2019). Additionally, a leatherback nesting in 2019 on Juno and Jupiter beaches, Florida, was hit twice by a boat during that same nesting season (Klingshirn 2021). The compounding effects of injury accruement in sea turtles are still unknown. Long-term goals of LMC's nighttime tagging program include continued annual monitoring of injury prevalence of nesting female sea turtles on Juno and Jupiter beaches, Florida, as this will allow for already tagged turtles to be examined for new injuries. For example, a loggerhead tagged in 2018 returned to Juno and Jupiter beaches to nest in 2020 with new boat strike injuries that prevented movement of hind limbs, thus impairing her ability to crawl properly and build a successful nest. Therefore, while the injuries observed in this study did not impact survival, this shows that they have the potential to reduce reproductive output, especially when the spinal cord is impacted.

Despite decades of conservation, loggerhead populations in Florida have shown minimal evidence of recovery (Ceriani et al. 2019). Further research on how injuries impact sea turtles is critical for their population growth. Archibald & James (2018) used a combination of in-water surveys and nesting beach

monitoring to generate leatherback injury data. Conducting in-water assessments provides data on males and individuals in other life-stage classes that do not come ashore to lay eggs. This approach would allow us to understand how different threats impact different life-stage classes of loggerheads. Fisheries bycatch is a main cause of mortality for juvenile and adult loggerheads in the northwestern and southwestern Atlantic subpopulations, whereas eggs and hatchlings are largely impacted by habitat alteration, pollution, and predation (Bolten et al. 2011, López-Mendilaharsu et al. 2020). Additionally, 5% of adults, 4% of subadults, and 1% of juvenile loggerheads entrained in the St. Lucie Nuclear Power Plant canal in Fort Pierce, Florida, had boat strike injuries (Norem 2005). Juvenile green turtles captured in northwestern Florida also had low boat strike injury prevalence at only 7% (n = 3 of 45; Perrault et al. 2021). This lower injury prevalence in smaller turtles suggests that larger turtles are more likely to survive boat interactions and/or that different life-stage classes experience different threats depending on their geographic location and behaviors (Bolten et al. 2011). Future studies should evaluate injury prevalence of loggerhead aggregations in less human-populated regions and investigate how sea turtle survivorship varies according to life-stage class, so that better management can be implemented to help loggerhead populations recover.

5. CONCLUSIONS

Most injuries found on nesting loggerheads in this study were classified as anthropogenic, with boat strike injuries accounting for the greatest percentage of identified injuries with known causes. This is similar to stranding data in Florida, where boat strikes significantly contribute to loggerhead mortality (Foley et al. 2015). Very few loggerheads from our study had entanglement or hook injuries, which were likely underestimated, but other studies showed that fisheries interactions do lead to mortality in both juvenile and adult turtles in the western Atlantic Ocean (Bolten et al. 2011, López-Mendilaharsu et al. 2020). Future research should evaluate injury prevalence on all life-stage classes and evaluate reproductive success of injured nesting loggerheads. Our results indicate that of the anthropogenic injuries, boat strikes were the most prevalent; therefore, we strongly recommend implementation of boating regulations in Florida state waters, especially during the nesting season, and on loggerhead turtle foraging grounds (Ceriani et al. 2017). In addition to boat speed restriction zones, vessel modifications, such as propeller guards and outboard jet motors, can be used to reduce boat-related injury to wildlife (Work et al. 2010).

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