Regionalization of scar patterns on the Florida Manatee (*Trichechus manatus latirostris*) observed at Harbor Branch Oceanographic Institute, Florida

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Abstract The Florida manatee (*Trichechus manatus latirostris*) is native to Florida and the Indian River Lagoon. Harbor Branch Oceanographic Institute (HBOI) is located on the Indian River Lagoon and is frequently visited by manatees. The Manatee Project was created in 2009 to document and photograph the manatees visiting HBOI. Analyzing photographs of 146 manatee that visited HBOI showed that a majority of the injuries sustained were caused by boats. This study found 97% of the manatee had at least one propeller injury and 31% of the manatee had at least one skeg injury. Other non-boat related injuries seen in the images included cold stress and entanglement injuries. The vast majority of scars were due to boat collisions. Propeller scars were found in 97% of the individuals examined in this study. The most prevalent injury locations were the left and right posterior back and left and right tail paddle.

Keywords Anthropogenic scarring, boat strike, entanglement, photo-identification, species conservation, vessel collision

Introduction

Manatees are large mammals that inhabit the air-water interface. Their long lifespan, use of nearshore aquatic habitats, and close proximity to boat traffic, unfortunately makes them susceptible to boat strikes. The native Florida manatee subspecies (*Trichechus manatus latirostris*) can be found along the Atlantic and Gulf coasts, including in Florida's Indian River Lagoon. In 1967, the Florida manatee was deemed endangered due to very low population numbers (estimated in the hundreds) and threats from human-related activities (U.S. Dept. Interior 1967; Ackerman 1995). Statewide aerial surveys started in 1991 only found 1267 individuals (FWC 2018). However, with recent increases in numbers to over 6600 individuals, the U.S. Fish and Wildlife Service (USFWS) has reclassified it as a threatened species (USFWS 2017).

Harbor Branch Oceanographic Institute (HBOI) is an important year-round site for Florida manatee as a designated manatee sanctuary, passive thermal refuge, source of food and freshwater, and quiet mating area; >500 of 3,488 manatees on

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Florida's east coast have been observed at HBOI (Goldsworthy 2016; FWC 2018; HBOI Manatee Project unpublished data). Some specific individual manatees are seen at HBOI in all seasons of the year. A few of these are manatees associated with the former Fort Pierce power plant and have seemingly remained locally (at least in terms of not being photographed at the nearest wintering sites surveyed in Coco Beach, Port Canaveral, Riviera Beach or elsewhere since the Fort Pierce power plant shut down in 2007) (pers. comm., Cathy Beck, USGS, 19 Sep 2017). Most other manatees only appear at HBOI during the spring or fall migration seasons, indicating that there is a partial migration taking place in the Florida manatee (Duetsch et al. 2003; Goldsworthy 2016).

Sirenians are not well adapted to cold water. They are slow-moving aquatic herbivores with exceptionally low metabolic rates and their distribution is primarily tropical (Irvine 1983). Their low metabolic rates and lack of a thick layer of blubber make the manatee vulnerable to cold stress. Chronic exposure to cold water below 20°C produces a cascade of clinical signs and disease processes termed "manatee cold stress syndrome" (Bossart et al. 2002, EAI 2002). Clinically, manatee cold stress syndrome involves a combination of skin lesions, emaciation, and infectious disease of the skin and gastrointestinal tract. These skin lesions can result in scarring on the manatee's skin. In order to avoid the colder waters during the winter, manatees migrate to warm water springs, canals and lakes that act as passive thermal refuges, and the warm water effluents of electric power plants and other industrial sources (Bossart et al. 2002). Manatees may rest in these warm water refuges for up to 7 days without feeding (Bossart et al. 2002).

During the coldest periods, 60% of all Florida manatees access the warmer waters near 10 of the state's electric power plants along the coasts and 15% use four natural springs; most others use thermal basins in southern Florida (Laist and Reynolds 2005). Site fidelity to these refuges appears to be the principal factor segregating manatees into at least four subpopulations (Laist and Reynolds 2005). Wintering away from a warm water refuge would be metabolically expensive for a manatee, and energy costs would increase at higher latitudes where average water temperatures are lower (Irvine 1983).

Manatee skin is a large organ with numerous complex functions essential for survival. It serves as a protective barrier against the environment, including, harmful chemicals, ultraviolet radiation, and pathogenic organisms; it also helps to produce vitamin D and regulate body temperature and moisture loss (Sood et al. 2014). Manatee skin is very thick, four times thicker than would be predicted for a terrestrial mammal with similar body mass (Kipps 2000; Lightsey et al. 2006). Kipps et al. (2002) did a study on manatee skin and calculated that it contributed 56 Newtons (N) of negative buoyant force, which equals 70% of the negative buoyant force of their dense pachyosteosclerotic ribs. The calculation of buoyant forces of the skeleton, skin, and lungs demonstrates that the manatee is positively buoyant at the surface and negatively buoyant at depths of less than 10 m (Kipps et al. 2002). The epidermis is thin and keratinous and interdigitates with the dermis, which is an organized three-dimensional weave that is reinforced with two sets of collagen fibers–radial and helical. The radial collagen fibers reinforce the skin against shear forces in nearly all directions, whereas helically wound fibers reinforce the circumference (Kipps et al. 2002).

Partly because of the skin's structure and composition, watercraft-induced wounds in manatees are often sublethal, with the protective dermis and underlying fat and muscle absorbing much of the impact, whether the impact is from blunt structures like hulls and keels or from sharp structures like propellers, skegs, and rudders (Lightsey et al. 2006). The thick layers of skin, fat, and muscle protect the manatee's internal organs and major blood vessels from the spinning propeller blades or skeg of the boat. The speed and size of the boat and the location of the manatee in the water column at the time of the boat strike result in varying degrees of injury to the manatee. These injuries range from superficial to full thickness wounds, involving the dermis and sometime muscle and bone (O'Shea et al. 2001). Blunt force trauma occurs when a part of the boat hull, such as the keel, hits the manatee. This often results in deep tissue damage and broken bones that are not necessarily visible at the surface; however, scrapes and scratches from barnacles, oysters, and other things on the hull surface may cause superficial wounds on the skin surface. Propeller strikes cause a series of parallel scars perpendicular to the direction of the boat's travel, whereas strikes by the skeg below a boat's propeller causes a long thin scar in the direction of the boat's travel.

Boats frequently hit manatees and this often leaves marks in their skin and, in some cases, completely removes sections of the skin or body (O'Shea et al. 2001). Manatees can be identified by their unique individual scar patterns and mutilations (Moore 1956; Beck et al. 1982; Beck and Reid 1995; Beck and Langtimm 2002; Barton and Reynolds 2006, 2008). One of the first references to manatees being struck by boat propellers was made in the early 1940s (O'Shea et al. 2001). The U.S. Geological Survey maintains a photo-identification database of manatees known as the Manatee Individual Photo-identification System, or MIPS (Beck & Reid 1995; Beck & Langtimm 2002; Langtimm et al. 2004). This photo-identification system and database of manatees contains information on distinguishable individuals with distinctive scar patterns. The vast majority of these appear to have been inflicted by propeller blades or skegs (O'Shea et al. 2001).

The Manatee Project at Harbor Branch Oceanographic Institute was established in 2009 (Nys 2010). Land-based observations and photo-identification techniques have been used over the past eleven years, allowing observers to document 529 individuals and recognize specific both migratory and more localized manatees that visit this location. Throughout the past eleven years, photos of the manatees observed at HBOI were sent to USGS researcher Cathy Beck to be compared to the MIPS database. So far, 120 of the manatees seen at HBOI have matched to individuals in MIPS (pers. comm., Cathy Beck, USGS, 23 Aug 2018). The available histories of many of the matching manatees indicate they are migrants using HBOI as a transient stopover point. However, MIPS was able to confirm that certain individuals have only been documented at HBOI and at the nearby former power plant in Fort Pierce indicating that there is a small seemingly local population (Goldsworthy 2016). There are a few challenges with using scar patterns for photo-identification. Superficial scars may eventually fade as wounds heal and acquire pigmentation again, and manatees may acquire new scars over time as they are struck by additional boats and these new scars may obscure previous ones.

Scar patterns have been used to identify individuals in photo-identification studies of marine animals, such as sea otters (Gilkinson et al. 2007), sharks (Barker and Williamson 2010), and groupers (Giglio et al. 2014). Rapid wound healing makes scar patterns more difficult to use in some species, such as manta rays (McGregor et al. 2019). More extensive manatee scars and mutilations have shown long persistence over many years (Beck and Reid 1995; HBOI Manatee Project unpublished data).

Manatees are not the only marine species to be affected by boat strikes. There are studies on dolphins (Bloom and Jager 1994), whales (Visser and Fertl 2000; Bradford et al. 2009; Hill et al. 2017), sharks (Speed et al. 2008; Domeier 2012), sea turtles (Oros et al. 2001), and dugongs (Maitland et al. 2006) acquiring injuries and then forming scars from contact with boat propeller blades and boat keels. These studies on animal-vessel collisions, especially on cetaceans, provide a model for the present analysis of regionalization of vessel collision scars (Bradford et al. 2009).

Prior studies looking at manatees, however, analyzed fatal watercraft-related mortality injuries (Beck et al. 1982, Wright et al. 1995). The Wright et al. study looked at the death of manatees from 1979 through 1991 and found that of the 628 manatees that died, 406 were due to collisions with watercrafts. They further determined that of the 406 deaths, propeller cuts caused 158 (39%); impact injuries (no propeller cuts) caused 224 (55%); propeller cuts and impact injuries, either of which would have been fatal, caused 16 (4%); and unidentified specifics of the collisions caused 8 (2%) (Wright et al. 1995). Fatal cuts were usually larger and longer than healed wounds. Many animals survived several boat collisions; one manatee had 22 separate patterns of propeller cuts (Wright et al. 1995). A necropsy performed by the FWC Marine Mammal Pathobiology Laboratory determined another manatee survived 49 different injury events; it was the 50^{th} injury that provided the fatal injury (Revkin 2002). This statement inspired part of the present project: How many boat strikes have living manatees experienced? Furthermore, this study also focuses on the individual number of scars on each manatee (a given boat strike can result in multiple scars). The Wright et al. 1995 study stated only 2% of the propeller strikes were to the head, but 98% were on the dorsum. In addition, nearly 90% of scar patterns were along the head-to-tail axis, indicating manatees were moving in response to the oncoming boat when struck (Wright et al. 1995).

A separate study by Tyler-Julian et al. (2016) found that manatees have a greater number of scars from boat strikes on the left side of the body. This may indicate a preferred direction to turn away from the oncoming boat.

The goal of this project was to evaluate causes of scars and the most common type of scars, scar regionalization on the manatees' bodies, how frequently manatees are injured in separate incidents, and to determine if there is a difference in injuries between sexes.

Figure 1. Map of the HBOI Channel and survey sites; the West Basin on the left and the Small Boats Marina on the right.

Materials and Methods

Research Site. Manatees have been seen at Harbor Branch Oceanographic Institute, in Fort Pierce, Florida, since a channel to the location was created before the 1970′s, but they were not consistently documented until 2009. The HBOI channel is a passive thermal basin, a confined area that retains heat from direct solar radiation or biodegradation of organic deposits (Smith 2000). In the case of the HBOI channel, and specifically the West Basin (Figure 1), the seawalls absorb solar radiation and transfer heat to the water, making it a passive thermal basin. Thermal data loggers show that the West Basin waters are a few degrees warmer than the data loggers out at the mouth of the ship channel in the Indian River Lagoon (HBOI Manatee Project unpublished data). In 2009, researcher Marilyn Mazzoil and intern Lauren Nys started the HBOI Manatee Project. From this initial project, a volunteer-run program collecting data on the manatees frequenting the channel was formed (Nys 2010; Robinson 2014; Goldworthy 2016). Twice-a-day photo-identification surveys were opportunistically conducted for a minimum of 15 minutes each at two locations. Data collected included photographs, later identified in the lab, as well as behaviors observed, time, date, weather conditions, and availability of fresh water from a pipe in the seawall. These surveys began in 2009 and have continued for the last eleven years.

HBOI has two main locations where manatees are most frequently seen, the West Basin and the Small Boats Marina (Figure 1). Both serve a number of functions for manatees, as a potential thermal refuge (especially the West Basin), a food source (both sites), a quiet space away from boat traffic in the lagoon (both sites), and a mating aggregation location (especially the Small Boats Marina) (Goldsworthy 2016). In addition to this, the West Basin has a small pipe where groundwater almost always enters the basin and serves as a fresh water source. During the winter, manatees aggregate in warm areas such as the discharge canals of power plants and passive thermal basins, with each manatee returning to the same refuge year after year (Deutsch et al. 2003, Laist and Reynolds 2005).

During preliminary surveys in 2009, there were three survey sites; however, since the barge docking area proved to be an area that few manatees visited, it was dropped from the Manatee Project survey effort (Nys 2010, Robinson 2014). The West Basin (N27.534° W-80.356°) and Small Boats Marina (N27.533° W-80.350) (Figure 1) were consistently surveyed over all eleven years. All surveys were conducted from land.

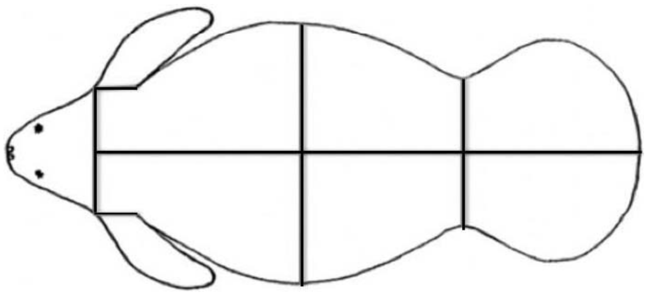

Figure 2. Subdivisions of the manatee body into the head, left flipper, right flipper, left anterior back, right anterior back, left posterior back, right posterior back, left tail paddle, and right tail paddle

Survey Effort. Beginning in 2009, volunteers arrived at HBOI and surveyed both sites twice per day, once during the morning shift, between 8:30–11:30, and once during the afternoon shift, between 13:30–16:30. For each shift, they visited both sites for a minimum of 15 minutes recording manatee behaviors and taking photographs of the manatees. All animals were photographed and recorded on our survey sheets. Three size classes were recognized adult, subadult, and calves.

Photo-Identification Procedure. Digital images of the manatees' backs and paddles are taken during the surveys when possible, using a Canon EOS-1D Mark II camera with a 100-400 mm zoom lens or a 17-35 mm zoom lens if the manatees were nearby. A simple point-and-shoot Panasonic Lumix DMC-ZS8 camera with 16x optical zoom, Nikon D3100 with 70-300 mm zoom lens, or Ricoh WG-5 GPS camera with 4x optical zoom were also available to the volunteers. On multiple occasions, there were opportunistic surveys in which photographs were taken of the manatees in the channel apart from the scheduled surveys. These individuals were also added to the database and a note was made of where and when the individuals were seen.

Distinct manatees observed at HBOI were recognized by unique scar patterns and mutilations of the tail paddle and given a 4-letter code. Calves have a 6-character code; they have a "c" for calf and then a number (c1 for calf 1, c2 for calf 2, etc.) before their name. If the calves were seen with their moms, they are given c1 or c2 and the mom's name. For example, calf 2 from mother SAWW is coded as c2SAWW.

Image Analysis. The photographs used in this study came from surveys conducted in the period from 2009-2018. Because manatees can acquire new scars or old scars can become obscured, this research project used one or two clear images of the entire adult animal taken at Harbor Branch. If two photographs were used, then they both must have been taken on the same day to eliminate any variability of scar healing or additional scars being present. These images must clearly show the entire body, with the exception of flippers, as they are not always photographed, but flippers that were documented were included in this study.

All image analysis and determination of scar types and locations were conducted by one analyst (LGG) to keep determinations consistent. Each manatee photograph was opened in ImageJ and a template dividing the manatee's body into nine areas of analysis was transcribed onto the photo. The body was subdivided into the following regions: the head, left flipper, right flipper, left anterior back, right anterior back, left posterior back, right posterior back, left tail paddle, and right tail paddle (Figure 2).

The individual's HBOI name, MIPS name (if known), and sex, presence (1) or absence (0) of scars in each of the nine anatomical regions, cause of injury (skeg, hull, entanglement, cold stress, propeller), total number of scars, and minimum number of injury events were recorded in an Excel spreadsheet. A set of parallel propeller marks were counted as a single injury event. The total number of scars is the total count of each mark caused by the skeg, hull, propeller, cold stress, and/or entanglement injury on the manatee's body. The cause of the scar was a post hoc observation based on the morphology of the scar itself. The manatee's scars are defined as: propeller strikes, indicated by a series of parallel scars; skeg

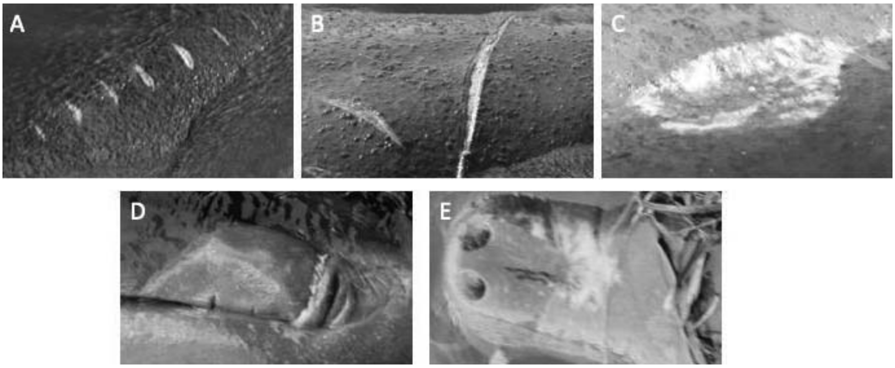

Figure 3. Representation of manatee scars: (A) propeller, (B) skeg, (C) hull, (D) entanglement, and (E) cold stress injuries. The manatee's scars are defined as propeller strikes, indicated by a series of parallel scars; skeg marks, indicated by one long relative straight line; hull strike marks where a wide patch of skin is missing; entanglement marks where an indentation around the entire animal or animal's flipper; and cold stress indicated by irregular white patches.

marks, indicated by one long relatively straight line; hull strike marks where a moderate to large single patch of skin is missing; entanglement marks where an indentation around the entire animal or animal's flipper; and cold stress indicated by random multiple white patches of variable size and shape which lack clean edges (Figure 3). While other types of scars were also considered, such as shark bites (Falcón-Mateos et al. 2003), no evidence of these were seen in the sample of photos examined. An analysis was run to determine if there is a difference in regionalization of wounds, a difference between sexes, and difference in the causes of each wound.

It is important to note that other superficial marks resulting from scrapes and cuts from objects in the environment, particularly minor cuts from the sharp edges of oyster shells or barnacles, were not included in this study. Any time a manatee is pushed against a dock, piling, or seawall in the estuaries, they are at risk of oyster shell or barnacle cuts. These are recognizable as very thin superficial cuts and scratches and often parallel in close proximity to each other; these are distinguishable from other types of wounds.

Statistical Analysis. Descriptive statistics were calculated using the total number of individuals examined as the denominator. A chi-square and Fishers exact test was used to compare the prevalence of scars and number of injury events by scar region and cause of injury. Number of scares and injury events between sexes were compared using a two-sample t-test. Animals with unknown sex were excluded from the comparisons of injuries by sex. All analyses were done using SPSS for windows, version 24. A p-value of < 0.05 was considered statistically significant.

Results

One hundred forty-six of 529 distinct manatees seen at Harbor Branch were included in our analyses. The criteria for the images used in this study were that the animals chosen were adults when they were photographed at Harbor Branch and had one or two clear images of the entire dorsum of the individual. Of the 146 manatees examined in this study, the sex of 51 animals was known; 37 were females and 14 were males.

Many of the manatees seen at Harbor Branch survived several boat strikes and formed scars where the boat propeller, skeg, and/or hull collided with the manatee. A minimum of 517 distinct injury events (set of parallel propeller marks, etc.)

Table 1. Prevalence of Scars in Anatomical Region for 146 Manatees Observed at HBOI

Head	L. Flipper	R. Flipper	L Ant. Back	R Ant. Back	L Post. Back	R Post. Back	L. Paddle	R. Paddle
10/146 7%	4/146 2%	3/146 2%	94/146 64%	88/146 60%	110/146 75%	105/146 72%	110/146 75%	99/146 68%

occurred in these 146 manatees producing a total number of 2,075 scars. The number of injury events in an individual manatee ranged from 1 to 14. The average number of injury events per animal was 4.6.

The manatees at Harbor Branch most prevalent injuries were from boat impacts. The majority of individuals, 142 (97%) seen at Harbor Branch had one or more propeller scars; 45 (31%) individuals had scars from at least one skeg injury; 33 (23%) manatees in this study had both skeg and propeller injuries. The total number of individual scars recorded on an animal ranged from 1 to 47 with an average of 14.2 scars per animal.

Of the 146 manatees observed at Harbor Branch, the most prevalent injury locations were the left posterior back (75%), right posterior back (72%), left paddle (75%), and right paddle (68%) (Table 1, Figure 4). The most common type of head injury was cold stress. No dominance for left- or right-side injuries was found.

Examining the other manatee injuries by individual cause showed 45 (31%) individuals had scars from at least one skeg injury; 21 (14%) individuals had at least one hull injury present; 2 (1%) individuals had scars from cold stress syndrome; 5 (3%) individuals had at least one entanglement injury (Table 2, Figure

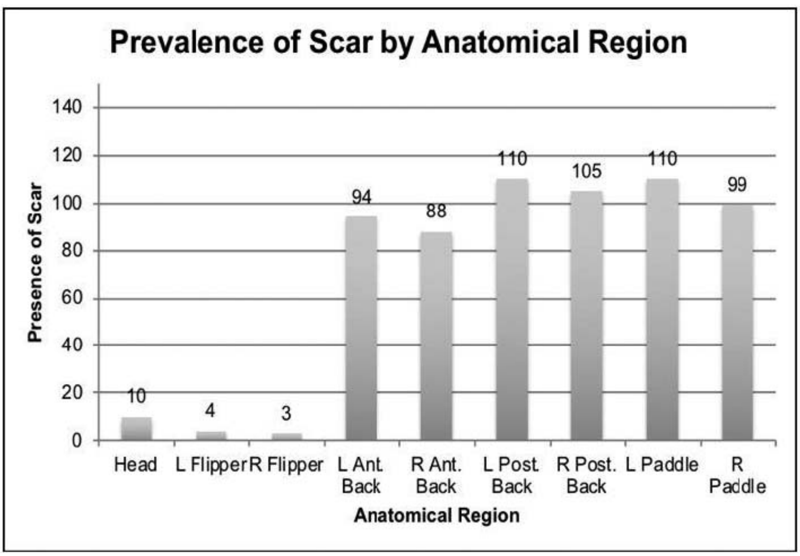

Figure 4. Prevalence of scars by anatomical region among 146 manatees observed between 2009-2018 photographed in the HBOI Channel.

Table 2. Cause of Injury for 146 Manatee Observed at HBOI between 2009-2018

Skeg	Hull	Entanglement	Cold stress	Propeller
45/146 31%	21/146 14%	5/146 3%	2/146 1%	142/146 97%

5). All five of these entanglement injuries were flipper injuries. Two of five manatees had entanglement injuries to both flippers.

The most common combinations of injuries include skeg and propeller 33 (23%); hull and propeller 14 (10%); 6 (4%) manatees had skeg, hull and propeller injuries (Table 3).

This study examined the differences of injuries between male and female anatomical regions. For the head, left flipper, right flipper, left anterior back, right anterior back, left posterior back, right posterior back, and left paddle there was no statistically significant difference in injuries for sex. However, for the right paddle, female manatees had a statistically significant increase in prevalence of injury than male manatees; 24 females had injuries in this location compared to 13 males. Table 4 has a detailed summary of the statistics for anatomical region and prevalence of injury in male, female, and unknown sex individuals.

In addition to the location of the injury, the cause of injury for 146 manatees observed at Harbor Branch was also recorded for each sex (Table 5). The total number of scars present on male manatees was 213, occurring from 66 different injury events. The total number of scars present on female manatees was 697, occurring from 168 injury events. The unknown sex individuals had 1,165 scars, occurring from 283 injury events. The mean number of total scars on a manatee from this population was 17.8, occurring from 4.6 injury events.

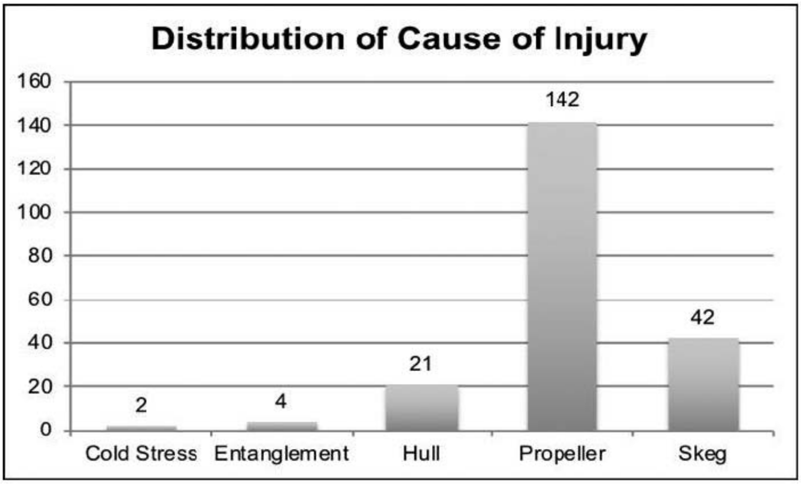

Figure 5. Occurrence of types of injuries among 146 manatees from HBOI between 2009-2018.

Table 3. Multiple Causes of Injury for 146 Manatee Observed at HBOI

Skeg & Propeller	Hull & Propeller	Entanglement & Propeller	Cold Stress & Propeller
33/146 23%	14/146 10%	3/146 2%	1/146 <1%
Skeg, Hull & Propeller	Skeg & Hull	Skeg, Cold Stress & Propeller	Skeg, Entanglement & Propeller
6/146 4%	2/146 1%	1/146 <1%	2/146 1%

Discussion

The overwhelming majority of injuries found in the present study were due to boat strikes, with propeller scars the dominant type. The structure of manatee skin may aid in surviving these multiple injuries (Kipps 2000; Kipps et al. 2002). The findings of this project are consistent with the article by O'Shea et al. (2001) who found the majority of injuries caused by boat propeller and skeg. Most of the animals with scars in the present study had evidence of multiple boat strikes. This may reflect the heavy boat traffic in the Intracoastal Waterway within the Indian River Lagoon. Similar results were seen in the Wright et al. (1995), many manatees survive multiple boat collisions, and one manatee had 22 separate patterns of propeller cuts. However, our sample size of 146 individuals is smaller than that of Wright et al. (1995) and O'Shea et al. (2001). A larger sample size of manatees of known sex is needed before additional conclusions can be made regarding sex differences.

Regarding locations of scars, there is a gradient of scar injuries starting with lower numbers of head and flipper injuries, with scars increasing in number on the anterior back, and continue to increase on the posterior back and paddle regions. The dominance of scars on the posterior body may indicate that the manatees were injured during the process of diving. This conclusion is consistent with the findings

Table 4. Sex Comparison of Injury Location for 146 Manatee Observed at HBOI

	Male n (%)	Female n (%)	Unknown* n (%)	χ^2 OR (p-value)
Head	2 (14.3)	1 (2.7)	7 (7.4)	2.46 (0.12)
Left Flipper	2 (14.3)	2 (5.4)	0 (0)	1.11 (0.29)
Right Flipper	1 (7.1)	2 (5.4)	0 (0)	0.56 (0.81)
Left Ant. Back	10 (71.4)	30 (81.1)	54 (56.8)	0.56 (0.45)
Right Ant. Back	9 (64.3)	24 (64.9)	55 (57.9)	0.97 (0.99)
Left Post. Back	12 (85.7)	33 (89.2)	65 (68.4)	0.12 (0.73)
Right Post. Back	12 (85.7)	30 (81.1)	63 (66.3)	0.15 (0.70)
Left Paddle	12 (85.7)	29 (78.4)	69 (72.6)	0.33 (0.56)
Right Paddle	13 (92.9)	24 (64.9)	62 (65.3)	3.99 (0.04**)
Total***	8.11 (4.99)	19.4 (13.6)	41.7 (29.9)	

* Unknown sex individuals were excluded from Chi-square comparison.
** Statically significantly difference at $p < 0.05$.
*** The mean and (standard deviation) are in place of the n (%) for total events.

Table 5. Sex Comparison of Cause of Injury for 146 Manatee Observed at HBOI

	Male n (%)	Female n (%)	Unknown n (%)	Total mean (sd)
Total # Scars	213 (10.3%)	697 (33.6%)	1165 (56.1%)	17.8 (11.2)
# Injury Events	66 (12.8%)	168 (32.5%)	283 (54.7%)	4.6 (2.8)
Cause of Injury	n (%)	n (%)	n (%)	
Skeg	6 (42.9%)	14 (37.8%)	25 (26.3%)	
Hull	2 (14.3%)	6 (16.2%)	13 (13.7%)	
Prop	14 (100%)	37 (100%)	91 (95.8%)	
Entangle	2 (14.3%)	3 (8.1%)	0 (0%)	
Cold Stress	0 (0%)	0 (0%)	2 (2%)	

Note: The mean and (standard deviation) are in place of n (%) for total number of scars and number of injury events. Total column for cause of injury n (%) includes males, females, and unknown sex.

of Nowacek et al. (2004) and Rycyk et al. (2018). During cold weather the manatee's body typically remain submerged and they only expose their head to breathe, which may help explain the cold stress head scars seen in our study. The numbers of boat-caused head injuries on living manatee is low because physical impact by boats is often fatal.

Finally, the known females observed at Harbor Branch had a mean number of scars (18.8) slightly higher compared to the known male manatees (15.2). There is a bias in recognizing female vs. male manatee because males can only be identified if they show their ventral side, and subsequently the genital slit location is noted; females can be identified this way but females can also be recognized while they are nursing a calf. However, conclusions about sex differences in scarring are limited given that sex of the individual was known in slightly more than one third of the manatees used in this study.

In the future, expansion of this project would include increasing the number of individual manatees sample size. It would be interesting to compare the manatee injuries at the Harbor Branch site to other sites (Crystal River, Blue Springs, Apollo Beach, etc.). Comparison of the regionalization of scars in these populations to the Harbor Branch population would provide information on whether or not the cause of injuries are the same or different in other Florida manatee populations. It would be interesting to see if the Harbor Branch population has a propeller injury bias because the manatee that visit Harbor Branch utilize the Indian River Lagoon, part of the intracoastal waterway, a high boat traffic area. Other less heavily trafficked locations than the Indian River Lagoon may have different proportions of scar causes. Policymakers and law enforcement can use this information to enforce slow speed zones and other policies to help protect these threatened marine mammals.

Different causes of injuries have different preventative solutions; therefore, it is important to determine the source of human-caused injuries so they can be prevented in the future. Looking at the manatees observed at Harbor Branch, propeller injuries were on almost all the animals. At first glance, identifying propellers as the main cause of injury demonstrates how policymakers and law enforcement might consider propeller guards. However, Wright et al. (1995) found

55% of the manatee mortalities from boat collisions involved blunt force trauma with the hull, whereas 39% of the mortalities could be attributed to cuts from propellers. Propeller guards would increase the number of blunt force injuries, but reduce most of the cutting injuries these manatees have endured. This action of adding propeller guards could counterintuitively increase boat collision mortalities. Other solutions, such as greater enforcement of manatee speed zones may more successfully reduce manatee injuries.

Acknowledgments Initial funding for the Manatee Project at HBOI came from a grant from the Save Our Seas license plate fund. A small grant from the FAU Office or Undergraduate Research also paid for some additional equipment. We also would like to thank Adam Schaefer for advice on statistical analyses.

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Submitted: August 17, 2020
Accepted: November 2, 2020