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Vessel strike mitigation lessons from direct observations involving two collisions between noncommercial vessels and North Atlantic right whales (*Eubalaena glacialis*)

David N. Wiley,[1] U.S. National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Stellwagen Bank National Marine Sanctuary, 175 Edward Foster Road, Scituate, Massachusetts 02066, U.S.A.; **Charles A. Mayo**, Center for Coastal Studies, PO Box 1036, Provincetown, Massachusetts 02657, U.S.A.; **Eden Marie Maloney**, Immunology Program, Stanford University School of Medicine, Stanford, California 94305, U.S.A.; **Michael J. Moore**, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02534, U.S.A.

Vessels can lethally strike whales and such strikes constitute a world-wide threat to large whales (Laist *et al.* 2001, Jensen and Silber 2003, Van Waerebeek *et al.* 2007). The threat is most serious for North Atlantic right whales (right whales hereafter), an endangered species with ~526 animals estimated alive in 2014 (Pettis and Hamilton 2015). On a per capita basis, right whales are the species most vulnerable to strikes (Vanderlaan and Taggart 2007) and vessel strikes are a major constraint to right whale recovery (Kraus *et al*. 2005, National Marine Fisheries Service 2005). Factors suspected of contributing to the vulnerability of right whales to strike include large (~15 m, 63,500 kg) body size, slow mean swim speed (≤1.9 km/h) (Hain *et al*. 2013) and 3.5 km/h (Mate *et al*. 1997), buoyant body (Nowacek 2001), use of coastal habitats with high volume shipping (Ward-Gieger *et al*. 2005), a tendency to feed close to the surface in some areas (Mayo and Marx 1990, Parks *et al*. 2011), and the need to breath at the surface.

Mitigation measures to protect right whales from strikes can involve separating whales and vessels in time and space (Vanderlaan *et al*. 2008, Wiley *et al*. 2013), human observers directing vessels away from whales (Wienrich *et al*. 2010), passive acoustic detection buoys that alert operators to the presence of whales (Van Parijs *et al*. 2009, Wiley *et al*. 2013), and slowing ships to modeled sublethal speeds (Vanderlaan and Taggart 2007, Wiley *et al*. 2011, Gende *et al*. 2011, Conn and Silber 2013). Mitigation efforts can benefit from direct observations of vessel strikes to whales, however, such instances are rare (Knowlton and Brown 2007). In this note, we report on two well observed right whale strikes. While each vessel is substantially smaller than a commercial ship, the lessons learned from these events can inform discussions about mitigating vessel strikes to large whales.

The first event occurred on 9 April 2009 in the Massachusetts Bay, USA (42°11.2′N, 70°33.7′W). The involved vessel was the National Oceanic and Atmospheric Administration (NOAA)/Stellwagen Bank National Marine Sanctuary research vessel R/V *Auk*, a 15 m, 27,215 kg displacement hydrofoil-assisted catamaran (Fig. 1a). The captain and mate were United States Coast Guard certified professional mariners and each had logged thousands of hours of ship time, often for projects involving marine mammal research. Also onboard were six experienced marine mammal scientists and technicians. Prestrike, the R/V *Auk* was transiting to port at a speed of 19.7 knots (36.5 km/h). Sea conditions consisted of northeast winds at 20–23 knots and wave heights of ~1.3 m. Three researchers were stationed on the flying bridge as marine mammal observers, with an unobstructed forward view. At ~1232 EST the mate, from a position inside the wheelhouse next to the captain, saw a white spot in the water ~9 m in front of the vessel, realized it was a whale and shouted “whale!” One observer on the flying bridge spotted what appeared to be ~15 cm of the left fluke of a whale protruding above the water ~1.2 m in front of the bow and one spotted a white patch in the water ~1.2 m in front of the bow. No blow had been observed prior to these observations. The observers did not have time to notify the captain and the captain did not have time to change course or speed prior to impact. Using the estimated distance of 9 m between whale and vessel at first sighting and a vessel speed of 19.7 knots (10.1 m/s), the time between sighting and impact would have been <1 s. Even doubling or tripling the initial sighting estimate would have provided only a few seconds reaction time before strike.

Immediately poststrike, observers were unsure if a whale or basking shark (*Cetorhinus maximus*) had been struck. While the captain assessed potential damage to the vessel, the observers searched for the struck animal. The whale was spotted “flailing” its flukes above the water and identified as a right whale. As the vessel had minimal damage, the captain moved towards the animal for observations and photographs to assess its condition and to allow individual identification of the animal from callosity patterns and body markings (Kraus *et al*. 1986). The animal was observed (ultimately confirmed by photographic analysis) to have 7–8 lacerations along the leading edge of the left fluke (Fig. 2a). There was minor bleeding observed at the site of the wound and no blood was observed in the water. At 1340 EST the R/V *Auk* departed the event location and reported the animal was swimming and diving “normally.” The struck whale was identified as right whale #3590 (a female born in 2005) and, since the event, had been seen 46 times through March of 2016.[2] Photographs taken 136 d poststrike showed a curling of the fluke in the wounded region (Fig. 2b) and 719 d poststrike showed the injured area missing and the wound healed (Fig. 2c).

The second event occurred on 9 April 2014 in Cape Cod Bay, Massachusetts, (41º46.8′N, 70º18.33′W). The involved vessel was the R/V *Shearwater*, a 13.1 m, 11 gross ton, twin engine Jarvis Newman power boat (Fig. 1b) operated by the Center for Coastal Studies (CCS), Provincetown, Massachusetts. Onboard were the captain and five scientists/technicians, all of whom were highly experienced and had spent hundreds of hours engaged in right whale research. CCS protocol required two spotters on the upper bridge continually searching for whales to be avoided. On the day of the event, sighting conditions were excellent with unlimited visibility and sea conditions of Beaufort one or less. Whale behavior in the area, as identified from right whale aerial surveys being simultaneously conducted, was subsurface feeding, with whales traveling an estimated 2–5 m below the surface with mouth open and dive intervals of approximately 8–15 min.

At 1349, while engaged in a plankton sampling transect (using a passive pipe scoop, subsurface sampling system) and traveling at nine knots (16.8 km/h), the vessel lurched as if striking an underwater object. There were no indications (*e.g.,* blow) of a whale in the near vicinity and observers had no prior cause to alert the captain. The struck whale rolled at the surface, close under the starboard bow. An observer in the wheelhouse window, standing next to the captain, thought that the visible body area was the left mid or lower flank, although a right whale's lack of a dorsal fin made body area identification difficult. The observer saw a white area on the skin, possibly a cut into the blubber, with blood in the water streaming over the cut, creating a red water plume approximately 0.6 m^2 in area. The white area appeared to be a cut approximately 20 cm in length. The team immediately undertook efforts to stay with the departing whale. No damage was observed on the flukes or tail peduncle and several photos were taken to be assessed for potential injury and for individual identification, although these body areas are not typically used for right whale identification (Kraus *et al*. 1986).

At approximately 1400, the team requested assistance from the organization's aerial survey team, which immediately redeployed to the area. The aerial team, staffed by trained and experienced scientists/photographers, circled the area and beyond for approximately 1 h and did not observe any animal with wounds. They photographed all whales in a wide area of the vessel. The vessel continued to search the area until 1700.

Neither vessel nor aircraft teams were able to locate and identify the whale, possibly because the wound was low on the left flank making it invisible when the whale was swimming upright. Neither team detected unusual behavior from the animals observed. Analysis of aerial photographs taken during the event failed to identify an animal with visible wounds and further documentation of the animal or its condition was not possible. A total of 86 individual whales were identified from aircraft photos to be in Cape Cod Bay on the day of collision. Of the 86 whales, 28 have not been resighted by CCS since the time of collision through 2015. However, no right whale carcasses with a similar wound have been documented poststrike and it is assumed that the animal survived.

These two observed collisions between a vessel and a right whale provide direct empirical information that can aid mitigation efforts. In each case the strike occurred despite the presence of a highly experienced captain and crew, and highly knowledgeable, dedicated observers. Preceding the collision, the whale was not seen or not seen in time for the vessel to take evasive action and the whale’s avoidance response, if any, was insufficient to avoid collision. In addition, sea state sighting conditions for the second event (Beaufort ≤1) indicate that strikes can occur even under ideal observing conditions.

While vigilance of dedicated observers is an important aspect of collision avoidance, our observations suggest that if vessels are operating in times and places of known or suspected right whale aggregation, even the most experienced captains and observers cannot be counted on to detect a whale in time to avoid striking the animal. Less experienced individuals could be expected to be even less effective at detecting whales in time to avoid collision. In addition, although each of the involved vessels was highly maneuverable, the brief period between initial sighting and collision (zero to a few seconds maximum) negated any attempts to use maneuverability to avoid the animal. Therefore, while vessel maneuverability can certainly be used to avoid whales observed at some distance and at some speeds, a ship's maneuverability alone does not assure collision avoidance. Furthermore, on each vessel observers had an unobstructed forward view with only a few meters distance to the vessel's bow. Vessels providing observers with more obstructed views and greater distance between observers and the bow could be expected to be even less efficient at spotting whales in time to avoid striking them.

Our observations also suggest that right whales should not be counted on to react in ways that avoid a collision at the speeds we report. This lack of response is consistent with known right whale behavior in the presence of ships (Nowacek *et al*. 2004). However, this does not mean that right whales always fail to detect and respond to vessels. One of us (DNW) has attached multi-sensor, suction-cup tags to right whales (Wiley and Goodyear 1998), which required close approach to the animals. From the vantage point of a "tuna pulpit" platform suspended 6 m forward of the 10 m tagging vessel's bow, he was able to observe the reaction of right whales to close (~10 m or less) vessel approach. If the whale was closely approached prior to arching for a terminal dive, it increased speed and fled horizontally in a series of twists and turns, staying near but below the surface, until the vessel backed off, after which it surfaced and dove. While the purpose of the approaches was tag attachment rather than assessing whale reaction to vessels, it was clear that at least some animals detected the vessel and reacted, but the vessel had to be very close (<10 m), and that their escape path and behavior left them vulnerable to being struck. In some cases, the feeding whale kept its mouth gaped with baleen visible, even as it fled, indicating a reluctance to stop feeding even when suspecting danger or, with its mouth filled with water, the whale was unable to exhaust water and close its mouth as it picked up swim speed. In any case drag caused by the open, water-filled mouth would reduce its maneuverability and escape speed. While these anecdotal observations could only be made under ideal sighting conditions (*i.e.*, observer suspended above the whale, sea state zero and no glare) they could represent an avenue of future research.

In light of these observations, we suggest that slowing ships to modeled sublethal speeds, such as required by the NOAA Ship Strike Rule (U.S. Federal Register 2008), is an important aspect of management actions to promote the recovery of right whales. This rule requires vessels of 19.8 m and greater in length to slow to 10 knots or less in specially delineated Seasonal Management Areas (SMA) and requests that vessels of this size voluntarily slow to 10 knots or less in Dynamic Management Areas created when observers locate right whales outside of an SMA (Clapham and Pace 2001). While each of the vessels described here is <19.8 m, we believe that the observations are still instructive. The inclusion of smaller vessels in speed management would also be important to protect right whales. In addition, the nonlethal interaction between the R/V *Auk* traveling at 19.7 knots and right whale #3590 should not be taken as a safe speed for smaller vessels (see below).

To place these events in a broader context, we conducted a retrospective analysis of right whales known to have been struck by unknown vessels. To accurately predict a particular case, data obtained from the North Atlantic Right Whale Consortium (NARWC) in 2007 were compared for photo identification of live sightings and from necropsy reports of vessel struck whales. Vessel-induced traumas fell into two categories: sharp propeller incisions and blunt impacts. Of lethal strikes (24), propeller-caused sharp trauma was responsible in 56% (15) of cases, while 20% (9) were attributed to blunt trauma. For propeller cuts, we analyzed fourteen dead and 24 survival cases and compared factors that could predict lethality. One lethally struck whale was excluded from the analysis because of ambiguity in the necropsy report.

We focused on location of trauma on the body (head, chest, back, peduncle, and fluke), and the depth, width, size, and number of cuts. Following Rommel *et al*. (2007), depth of cut was estimated by the degree to which the incision showed a sinusoidal or reverse sinusoidal shape. We constructed a matrix using location of the cut; head, chest, back, peduncle, or fluke; size of the cut on a range of small (score = 1), medium (2), and large (3); and depth of the cut on a range of very shallow (1), shallow (2), moderate (3), deep and through fluke (4), and very deep (5). The score was calculated by totaling the product of the number of cuts, size and depth for each body part. After ranking each case, we used a binary logistic regression to predict lethality of the 38 cases. The model predicted an event's membership into the alive/dead group with 86.8% accuracy ($P < 0.001$). For visualization, a collage for lethal cases and another for nonlethal cases was created based on drawings and photographs from the necropsy reports and NARWC

(Fig. 3).

Projecting the wound locations from Event #1 onto our collage indicate a nonlethal injury, as has been born out from subsequent observations. However, had the lacerations been closer to the midline of the flukes, a major artery could have been severed resulting in near immediate mortality (Fig. 3). While good documentation of the wounds from Event #2 are lacking, the suspected lateral flank location suggest that the strike could have been fatal if caused by a more powerful, larger or faster moving vessel (Fig. 3).

In summary, the use of even the most experienced crew and dedicated observers cannot always be relied upon on to detect and avoid striking right whales and possibly other species as well. In addition, the short reaction time that can precede a strike can negate any dependency on vessel maneuverability to avoid collision. Until more sophisticated mitigation measures can be developed, in situations where whales and vessels cannot be separated in time and space, the use of trained/informed crew and observers combined with the slowing of ships to modeled sublethal speeds is the most reliable way to avoid lethal strikes.

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Figure 1. (a) R/V *Auk* and (b) R/V *Shearwater*.

Figure 2. (a) Struck right whale from Event#1 showing wounds to fluke tip consisting of 7–8 lacerations at the time of strike, (b) fluke condition 136 d poststrike, and (c) fluke condition 719 d poststrike showing healed wound and missing left fluke tip.

Figure 3. Sharp trauma (propeller strike) collage based on 38 cases (14 mortal and 24 survived) showing characteristics of lethal and nonlethal propeller wounds. Superimposing the approximate location of wounds from Event #1 (red square) indicate a nonlethal wound, as was born out be subsequent observations. However, a wound closer to the midline of the flukes could have resulted in a fatal strike. Superimposing the suspected wound location from Event #2 (red circle) indicate that the strike could have been lethal, had a larger or faster moving vessel been involved.

[1] Corresponding author (e-mail: david.wiley@noaa.gov).
[2] Personal communication from Heather Pettis, New England Aquarium, One Central Wharf, Boston, MA 02110, 6 April 2016.

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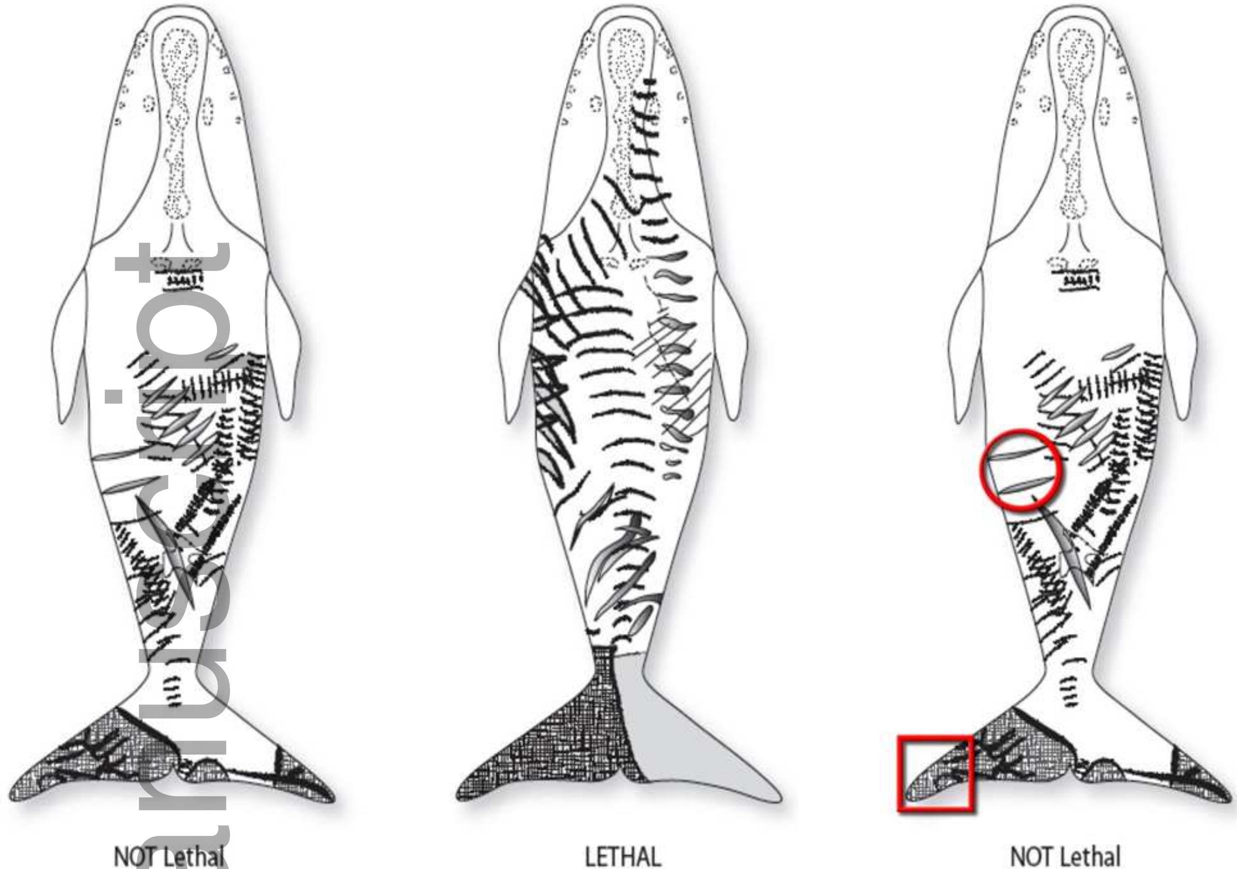

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