Impact of Baleen Entanglements on the North Atlantic Right Whale

Brandon R. Finch '26 and Alexander J. Werth

Department of Biology, Hampden-Sydney College, Hampden-Sydney, VA 23943

Abstract

North Atlantic right whales are at their lowest recorded numbers ever. Their dwindling numbers are mainly attributed to entanglements and negative life-altering interactions with humans. This study examined photographs of entangled right whales and their baleen plates to better understand how entanglements impact right whales' abilities to feed and survive. Research indicated that right whales are most commonly entangled in their mouths, and mouth entanglements are deadly because of consequential starvation, stress, and exposure to disease. This study also found that though baleen may bend over the course of an entanglement, it is elastic in nature and quick to grow back into place once freed from rope. The baleen plates were also found to naturally have gaps appearing intermittently during feeding.

Introduction

The importance of researching North Atlantic right whales is now more important than ever before as their population dips to below 500 individuals (Howle et al., 2019) . The growth of human populations and ocean-oriented industries have widely increased human-whale interactions, rendering these encounters more common and deadly. A significant contributor to these human-whale interactions is the commercial fishing industry. As human populations grow, the need for ocean-caught food sources grows, too. In other words, fisheries across the world are expanding to account for greater food needs (Cassoff et al., 2011). The expansion of these commercial fisheries, however, places greater amounts of fishing gear in waters home to North Atlantic right whales, and this change creates chances for a higher number of whales to become entangled in fishing gear each year (Cassoff et al., 2011).

North Atlantic right whales are mysticetes (Goldbogen et al., 2017). Mysticetes are a group of whales that utilize baleen plates to filter small copepods and other microorganisms out of engulfed water (Goldbogen et al., 2017). These baleen plates consist of keratin, the same type of fiber that makes up fingernails and hair in humans (Goldbogen et al., 2017). To best facilitate filter feeding, these baleen plates are highly flexible and elastic when hydrated (Potvin & Werth, 2024). Furthermore, the level of flexibility of the baleen plates is directly impacted by the porosity, or how tightly woven the keratin fibers of the plates are (Potvin & Werth, 2024). The porosity and flexibility of these plates change from the anterior to posterior sections of the mouth to account for different flow rates of water through the baleen (Potvin & Werth, 2024). These flow rates change throughout the different regions of the mouth to allow for right whales to undergo their method of filtration feeding known as cross-flow filtration (CFF) (Goldbogen et al., 2017). The mechanism by which CFF works is complicated and is thought to involve the flow of prey-laden water parallel to baleen plates (Goldbogen et al., 2017). The parallel flow of water across the baleen would reduce the amount of buildup or "clogging" of prey in the baleen and, therefore, negate the need for physical or mechanical removal of food from baleen plates (Goldbogen et al., 2017).

Grown North Atlantic right whales can reach a length of up to 52 feet and weigh upwards of 70 tons (NOAA Fisheries, 2024). In order to fuel their massive bodies, North Atlantic right whales spend a large portion of their time feeding. North Atlantic right whales, like bowhead whales, feed via a mechanism known as continuous ram filter feeding (Goldbogen et al., 2017). Continuous ram filter feeding consists of the whale swimming at low speeds with its mouth agape for minutes at a time to capture plankton and other microorganisms within its baleen (Goldbogen et al., 2017). Once the water enters a North Atlantic right whale's mouth, the intake of water will then be subject to cross-flow filtration, as mentioned earlier. However, the amount of time that North Atlantic right whales spend feeding with their mouths open can render them vulnerable to entanglement in a growing amount of fishing gear in their habitat.

Entanglement is potentially the most threatening obstacle to recovering right whale populations. Some studies indicate that 89% of all living right whales have been entangled at least once in their lifetime (Reed et al., 2024). Furthermore, there are some records that indicate that certain North Atlantic right whales may have experienced up to eight entanglements over the course of their lives (Reed et al., 2024). An entanglement usually consists of a whale being wrapped in industrial fishing rope/line that was attached to a buoy and used to retrieve crab or lobster traps on the ocean floor. In Figure 1 below, one may see how even the buoys attached to fishing gear may become entangled in a whale's mouth in select circumstances. In entanglements involving industrial and commercial fishing rope, the mouth is the most common place for ropes to entangle a whale (Cassoff et al., 2011). The mouth is commonly entangled because of the extended periods of time that whales spend with their mouths open to feed, but all parts of a whale may become entangled in fishing ropes.

Figure 1: North Atlantic right whale 2212 became entangled with a buoy in its mouth presumably after feeding with its mouth agape (National Science Foundation et al., 2024).

Because these ropes are heavy duty to support and retrieve fishing gear that can weigh thousands of pounds, the ropes and gear, if still attached, have the potential to increase the whale's drag in the water by 1.5–3.1-fold (van der Hoop et al., 2017). Not only would this extra resistance make swimming more difficult, but feeding, mating, migrating, and giving birth would also be extraordinarily more difficult. All entanglements increase the amount of physical stress felt by a whale, but a severe entanglement has been found to cause levels of stress that mimic an additional migration or even birthing event (van der Hoop et al., 2017). Entanglements are not easy to be freed from. Records show that a whale may be entangled from several months to over a year if humans cannot intervene to free the whale (van der Hoop et al., 2017). These intervention efforts are great in some circumstances, but the nature of these disentanglement missions is dangerous. As can be seen in Figure 2, small boats must be driven dangerously close to the whale in an attempt to disentangle the rope. These whales, however, may misinterpret the help from humans as further danger and capsize the rescuers' boat in self-defense.

Figure 2: Rescuers attempt to pull rope from EGNo 3911. Their efforts are unsuccessful, however, and the whale ends up dying several months later (National Science Foundation et al., 2024).

Entanglements are not only stressful to whales, but they may be fatal too. A leading cause of death by entanglements is drowning (Cassoff et al., 2011). North Atlantic right whales are mammals, so they must breathe air through two blowholes located on the tops of their heads. If the right whale becomes entangled in fishing gear subsurface, however, and is unable to free itself, then there is the possibility that the whale may not be able to resurface to breathe. Another way in which entanglement may cause death is through starvation (Cassoff et al., 2011). As stated previously, the physical stress put upon an entangled whale is astronomical, and this kind of stress can cause a whale to become emaciated. If a whale cannot feed effectively and is burning a greater number of calories than the whale can consume, then energy stored in the body in the form of blubber will be depleted until the whale starves to death (van der Hoop et al., 2017). A final mechanism by which entanglement may cause death is through disease and pathogens (Cassoff et al., 2011). The ropes that hold crab and lobster pots are made of thick and durable rope that can easily exceed several centimeters in diameter. In fact, necropsies on deceased right whales have indicated that fishing gear can cut as deep as 20 cm into the whale (Cassoff et al., 2011). As friction and tension from swimming drive these ropes deeper into the flesh of the whale, deep lacerations and tears in the flesh may occur (Cassoff et al., 2011). Figure 3 below illustrates wounds on the rostrum of a North Atlantic right whale that were recorded as being "raw" for seven months following entanglement (National Science Foundation et al., 2024). These wounds remain raw and susceptible to disease or parasites until the whale becomes disentangled. Unfortunately, if the whale is not freed in time in any of these cases, then the whale may die (Cassoff et al., 2011).

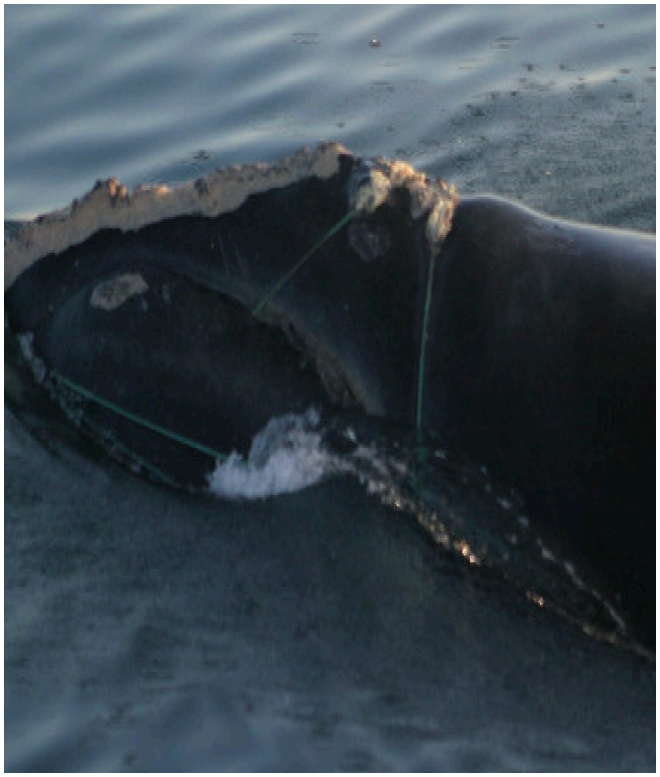

Figure 3: EGNo 3314 experienced an entanglement with ropes wrapping tightly around its rostrum for many months. Even after being freed, the ropes leave deep and fresh wounds that are susceptible to infection (National Science Foundation et al., 2024).

Because the mouth is the most commonly entangled part of a whale, this research project was focused on looking at the impact of mouth entanglements on North Atlantic right whales and their ability to survive and feed during and post-entanglement. Understanding the mechanism by which right whales entangle their mouths and the most common location in their mouths for entanglement proves important for determining how humans may reduce the number of entanglements whales face. An example of the applicability of this research can be drawn from previous research on entanglements being used to pioneer "ropeless" fishing equipment that keeps horizontal fishing lines out of the water column to better prevent entanglements (Moore, 2019). Additionally, understanding the severity of mouth entanglements could be important information for helping humans in their whale disentanglement efforts. Finally, understanding entanglements of a whale's mouth can shed light on the importance of baleen positioning and movement during filter feeding.

Through the examination of photographs and videos of both healthy and entangled North Atlantic right whales, one may be able to see the differences in the quality of life and efficiency of feeding of these whales. These differences may be judged based on the presence or lack of damage to the baleen, scarring on the rostrum and body, emaciation, and other wounds associated with entanglement. Additionally, looking at photos of a North Atlantic right whale's condition before, during, and after an entanglement can shed light on the physical toll of entanglement on the whale during the different parts of this "life-history stage" (van der Hoop et al., 2017). All of this information, though, may be used to better understand the negative impact that mouth entanglements have upon North Atlantic right whales.

Therefore, the hypothesis for this research stated that if a North Atlantic right whale were entangled in the mouth by fishing gear, then the whale's ability to survive and feed would be hindered to the point of severe emaciation or death.

Materials and Methods

For this research, photographs of North Atlantic right whales were gathered from multiple sources. One collection of photographs was provided by Gina Lonati, a PhD student at the University of New Brunswick. Dr. Michael Moore of the Woods Hole Oceanographic Institution and his colleagues Monica Zani and Carolyn Miller also granted access to private drone photos and footage of North Atlantic right whales. Dr. Moore's photos and Zani's videos were taken on the same day by a DJI Inspire 2 drone and a DJI Mavic 3 drone, respectively. Lastly, the North Atlantic Right Whale Consortium (NARWC) and the New England Aquarium's Anderson Cabot Center for Ocean Life (ACCOL) granted access to their database of right whale photos and injury reports for review and reference.

The individual collections of photos and videos were analyzed for evidence of entanglement. When possible, a collection of pictures taken over the course of many years was referenced to search for any kind of lasting impact or evidence of entanglement. The images sourced from the NARWC were additionally cross-referenced with injury reports and necropsy results to see the number and frequency of entanglements experienced by individual whales. Images from any of these sources that showed unique and specific signs of entanglement were added to a slide show and spreadsheet to be cataloged for reference later. The PowerPoint was used as an image bank for instructional and impactful images, and the spreadsheet was used to sort the different kinds of images being shown in the PowerPoint. Both collections were made in an effort not only to organize information for this project but also to build a collection of resources and images for future research in this field.

These photographs were examined with the following interests in mind:

- Severity of entanglements
- Frequency of entanglements
- Body part(s) most commonly affected by entanglement
- Age of entangled whales
- General health of whale; are they emaciated?
- Geographical location of entanglement/travel
- Consequences of entanglement
- Socialization and group behavior
- Real-time flow of water through whale's mouth and fluidity of baleen plates

In the slide show and spreadsheet, the whale's overall health, location of noteworthy scars and injuries, presence of calf, duration, number of entanglement(s), and date of death, if applicable, were noted. For whale injuries to be cataloged as injuries due to entanglement, evidence of entanglement was defined as damage to tissue, scarring of tissue, or damage of baleen plates that were consistent with damage that could be caused by ropes or other fishing debris in the ocean. The occurrence of an ongoing or active entanglement was also important to note in the spreadsheet. An active entanglement was defined as a whale that was entangled in rope or other fishing debris at the time the photo was taken.

To analyze additional footage of the North Atlantic right whale and understand the politicization of the entanglement of North Atlantic right whales, the documentary Entangled: The Race to Save Right Whales from Extinction (2020) directed by David Abel was referenced.

Results

Upon analysis of thousands of pictures of both healthy and entangled North Atlantic right whales, it is clear to see that entangled whales are in poorer bodily condition than non-entangled whales. Deterioration of physical condition caused by entanglement can be seen distinctly in photographs of North Atlantic right whale EGNo 3911 in an entanglement that ultimately caused the death of the whale (National Science Foundation et al., 2024). Figure 4 shows a picture taken on January 23rd, 2010, of the young whale swimming pre-entanglement. The whale is young but looks to be in good health with a plentiful layer of blubber. Figure 5, however, shows the North Atlantic right whale dead at sea from malnourishment caused by entanglement (National Science Foundation et al., 2024).

Figure 4: EGNo 3911 swims unencumbered and healthy on January 23rd, 2010, (National Science Foundation et al., 2024).

Figure 5: EGNo 3911 is spotted dead at sea and severely entangled. Whale looks emaciated and thin due to entanglement that ultimately caused death (National Science Foundation et al., 2024).

Entangled whales, such as EGNo 3911 above, were typically thinner and more emaciated in appearance, whereas non-entangled whales had fuller bodies. On average, entangled whales were found dead from emaciation or vessel strikes at a higher frequency than non-entangled whales. North Atlantic right whales EGNo 3694, 2301, and 1238 are three high-profile whales found dead due to confirmed entanglements since 2001 (National Science Foundation et al., 2024). North Atlantic right whales EGNo 2151, 3210, and 3311 are three more whales presumed dead due to entanglement after they were photographed with declining health and not seen since (National Science Foundation et al., 2024). It was also found that most whales noted in the NARWC database were entangled multiple times. North Atlantic right whale EGNo 1427 has been entangled six times, EGNo 2212 has been entangled five times, EGNo 2320 has been entangled 3 times, EGNo 3311 was entangled three times in its six years of life, EGNo 3333 has been entangled five times, and EGNo 3420 has been entangled three times (National Science Foundation et al., 2024).

Photos indicate that baleen has the elasticity and flexibility to bend back into its proper shape after entanglement in fishing gear. North Atlantic right whale EGNo 2427 was severely entangled in the mouth, causing the baleen to break and bend outside of the mouth (National Science Foundation et al., 2024). The damage was first observed in Figure 6 on July 20, 2001, but the damage was completely resolved by the next observation of EGNo 2427 in Figure 7 on March 27, 2003 (National Science Foundation et al., 2024).

Figure 6: Earliest photo of entanglement and damage to EGNo 2427 taken on July 20, 2021, (National Science Foundation et al., 2024).

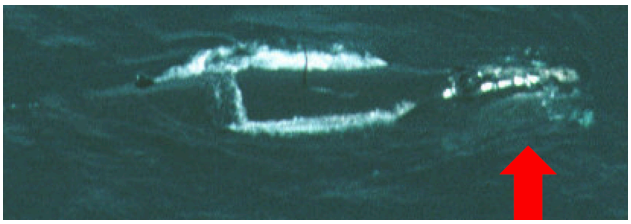

Figure 7: The next recorded sighting of EGNo 2427 on March 27, 2003. Red arrow points to healed rostrum and baleen. (National Science Foundation et al., 2024)

Regarding mouth entanglements, photos indicate that any area in the mouth is just as likely to be entangled as another. In the image bank put together for this research, 19 out of 28 pictures looking at baleen gaps or damage from suspected entanglement show damage or disturbance only to the front and middle third of the mouth. Another 9 out of 28 pictures show damage or disturbance to the posterior third of the mouth. Each third of the mouth (anterior, middle, or posterior) is just as susceptible to entanglements while the whale swims with its mouth agape. Damage resulting from entanglement that is isolated to the anterior portion of the mouth may be observed in Figure 8, but Figure 9 illustrates a fatal entanglement affecting both the anterior and posterior portions of the North Atlantic right whale's mouth.

Figure 8: North Atlantic right whale 2151 was entangled by fishing line that cut through the rostrum and baleen, as indicated by the red arrow. Damage caused only to the anterior portion of the mouth. (National Science Foundation et al., 2024).

Figure 9: North Atlantic right whale 3694 was found dead at age 10 due to entanglement. Ropes entangled baleen from anterior to posterior of mouth (National Science Foundation et al., 2024).

Discussion

These different findings are critical to the field of North Atlantic right whale research. The confirmation that entanglement can cause emaciation is especially important because this finding confirms the idea that right whales face physical stress and have to put forth greater effort to function as they need to for survival. The extent to which entanglements impact whales' physical condition is sometimes debated, but the pictures showing the shrinking blubber content and body size over just several months of entanglement demonstrate the physical harm and stress that entanglements can cause. These pictures also illustrate how entanglements can be considered an animal rights issue. The idea of these creatures starving to death due in part to human negligence is concerning, to say the least. If nothing else, these pictures should give humans a sense of empathy for the suffering faced by these whales in entanglements. These concerns have led to fisheries being closed for certain months as North Atlantic right whales migrate through. Though these closures may act as a good short-term solution, these closures prevent many

fishermen in the northern United States and southern areas of Canada from struggling to make a living. This battle to support fishermen while simultaneously protecting North Atlantic right whales points to ropeless fishing gear potentially being the future of fishing.

The genius of ropeless fishing gear is that it utilizes the same general traps that are currently used by the industrial market. The main difference, though, is that there is no longer a buoy and rope dangling in the water for extended periods of time. The vertical line and buoy are attached directly to the trap until the trap owner sends a digital or acoustic signal to the trap to release the buoy and rope for trap retrieval (Lambert, 2023). This technology will surely prove critical to saving whales from becoming entangled in long vertical lines in the future. Figure 10 illustrates the length of rope that whales may become entangled with when vertical lines are hanging slack in the water.

Figure 10: North Atlantic right whale was spotted entangled around the mouth on February 16, 2014. This line trailed far behind the whale and was around 100 ft in length (National Science Foundation et al., 2024).

The finding that many whales become entangled multiple times over the course of their life is also important. In some cases, whales become entangled an average of every two to five years. The frequency at which these life-altering events occur is concerning, considering all of the damage and stress that these entanglements can cause to whales. The reason for these repeat entanglements can be attributed to right whales sharing a habitat with other ocean-dwelling species, like crabs and lobsters, that are heavily fished for (Whale and Dolphin Conservation USA, 2024). Additionally, the filter feeding of right whales involves swimming with the mouth agape for extended periods of time. This mechanism of feeding, as previously discussed, renders the whales more vulnerable to fishing lines hanging vertically in the water column. These overlaps in fishing areas and right whale habitat, once more, point to ropeless fishing gear being a good compromise to both saving whales and saving fishermen's way of life. As stewards of the ocean, humans should be able to use the ocean's resources to their advantage as long as they are using them responsibly and attempting to mitigate negative interactions with other creatures.

The finding and confirmation of baleen's ability to heal quickly and be elastic is promising. The ability of North Atlantic right whales to recover quickly from mouth entanglements may make the difference between their species recovering and dying off. If a right whale is able to free itself from a mouth entanglement, then the ability for the whale's baleen to flow back into place and heal quickly will allow the whale to feed normally in order to regain strength and weight that may have been lost in the midst of entanglement. The ability of baleen to rebound into the mouth after damage is critical to the whale feeding properly and fueling its body for recovery. The flowing and elastic nature of baleen may also indicate that gaps in baleen plates may not be detrimental to health but rather just a natural imperfection in baleen plate growth. Though baleen's elasticity is an advantage for healing and feeding, the flexibility of these plates may make it easier for ropes to become more aggressively knotted within the mouth. The ability for knots to form within the baleen may be seen in Figure 11. These knots take months to years to wear out of the mouth, and this timeframe of freedom is not promising for right whales. The ability of rope to be woven and knotted into baleen fringes and plates highlights why mouth entanglements are so dangerous for right whales.

Figure 11: North Atlantic right whale 2301 found dead from entanglement with gill net line "cleated" into baleen plates (National Science Foundation et al., 2024).

Conclusion

A lot of useful information was better understood from this research. Not only were some consequences of entanglement confirmed, but potential solutions to entanglement, such as ropeless gear, now seem more applicable than ever. This research is not done by any means, but the collection of photographs and videos put together for the image bank is a good start to understanding and cataloging damage to right whales and their baleen. In the future, more photographs can be sifted through to have a larger image bank to pull from. A larger collection of images would provide more evidence of the dangers of entanglement and can also serve to see more trends related to entanglement. Additionally, in combination with putting together a larger image database, in-lab research and experimentation could be done to confirm theories about entanglement. Work that looks at water flows through the baleen, the ability of the rope to become caught in the baleen, and the impact of gaps or missing plates in baleen on feeding would all contribute to a more well-rounded understanding of the importance of baleen in filter-feeding for the right whales. This sort of research is currently being done at Hampden-Sydney College in Farmville, VA, by Dr. Alex Werth, and it is yielding these kinds of results already.

References

Cassoff, R. M., Moore, K. M., McLellan, W. A., Barco, S. G., Rotstein, D. S., & Moore, M. J. (2011). Lethal entanglement in baleen whales. *Diseases of Aquatic Organisms*, *96*(3), 175–185. https://doi.org/10.3354/dao02385

Goldbogen, J. A., Cade, D. E., Calambokidis, J., Friedlaender, A. S., Potvin, J., Segre, P. S., & Werth, A. J. (2017). How Baleen Whales Feed: The Biomechanics of Engulfment and Filtration. *Annual Review of Marine Science*, *9*(1), 367–386. https://doi.org/10.1146/annurev-marine-122414-033905

Howle, L. E., Kraus, S. D., Werner, T. B., & Nowacek, D. P. (2019). Simulation of the entanglement of a North Atlantic right whale (Eubalaena glacialis) with fixed fishing gear. *Marine Mammal Science*, *35*(3), 760–778. https://doi.org/10.1111/mms.12562

Lambert, L. (2023, June 8). *North American lobster industry confronts "ropeless" traps after whale entanglements*. Reuters.

Moore, M. J. (2019). How we can all stop killing whales: A proposal to avoid whale entanglement in fishing gear. *ICES Journal of Marine Science*, *76*(4), 781–786. https://doi.org/10.1093/icesjms/fsy194

National Science Foundation, New England Aquarium, & Parallax Consulting. (2024). *Digital Information Gathering and Information Tracking System (DIGITS)* (4/25/2024).

NOAA Fisheries. (2024). *Species Directory* . North Atlantic Right Whale.

Potvin, J., & Werth, A. J. (2024). Suffused: baleen fringe mat porosity and hydrodynamics in balaenid and balaenopterid whales. *Biological Journal of the Linnean Society*. https://doi.org/10.1093/biolinnean/blae030

Reed, J., New, L., Corkeron, P., & Harcourt, R. (2024). Disentangling the influence of entanglement on recruitment in North Atlantic right whales. *Proceedings of the Royal Society B: Biological Sciences*, *291*(2018). https://doi.org/10.1098/rspb.2024.0314

van der Hoop, J., Corkeron, P., & Moore, M. (2017). Entanglement is a costly life-history stage in large whales. *Ecology and Evolution*, *7*(1), 92–106. https://doi.org/10.1002/ece3.2615

Whale and Dolphin Conservation USA. (2024). *Deep Dive: Right Whale Entanglements*.