Modeling the effect of vessel speed on Right Whale ship strike risk

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Summary

Vessel speed restrictions have three potentially beneficial effects on the risk of right whale ship strikes: a better chance for the whale to avoid the ship, a better chance for the crew to spot and avoid the whale, and less energy imparted to the whale in the event of a collision. We have developed a model of the first of these effects, using data from observed encounters of right whales with vessels and from whale diving activity.

Using a probabilistic description of right whale response based on these observed behaviors, we estimate the likelihood of a strike given that the ship is initially on a collision course with the whale. Model results suggest that more than half of right whales located in or swimming into the path of an oncoming ship traveling at 15 knots or more are likely to be struck even when they do take evasive action. The model also suggests that the strike risk posed by a conventional ship moving at 20 to 25 knots can be reduced by 30 percent by slowing to 12 or 13 knots, and by 40 percent at 10 knots. Whales are likely to be largely safe from ship strike if they detect and react to an oncoming vessel at a distance of 250 m or more. Strike risk is considerable if the detection distance drops below 100 m.

Background

As many as 75 percent of known anthropogenic mortalities of the North Atlantic Right Whale (*Eubalaena glacialis*) likely resulted from collisions with large ships ("ship strikes") along the US and Canadian eastern seaboard. Although the number of documented ship strikes is small, the right whale is a highly endangered species, and losses of any individuals from the population are taken seriously. To address the issue of ship strikes, NOAA published on 6/26/2006 a set of proposed rules for right whale ship strike reduction (Federal Register 71:36299). The proposed rules consist of a combination of routing restrictions, areas to be avoided, and speed restrictions for vessels along the US east coast.

Under such a management regime, vessels entering a management area would be required either to keep their speed below an established limit, or to reroute around the area. The argument for route restrictions is clear: where right whale population density is reasonably well understood, and traffic can be rerouted away from areas known to contain aggregations of right whales, appropriate rerouting has been shown to reduce the risk of ship strikes. For example, the Bay of Fundy (Canada) Traffic Separation Scheme was amended in 2003 to reroute vessel traffic through areas with lower right whale densities (Brown *et al*. 2007). The justification for speed restrictions is more problematic, because it relies primarily on the assumption that right whales can better avoid ships moving at slower speeds – a point about which there is some uncertainty and little consensus. The work we have carried out here begins to clarify what can reasonably be projected about the effect that vessel speed and size may have on a whale's chance of avoiding a collision.

Model

Our objective is to model the trajectories of a ship and a whale under different ship speed and whale response assumptions to determine the effect of vessel speed and size on the likelihood of collision under plausible statistical assumptions about whale response. To do this, we model the relative position of a ship and a whale as a function of time. We begin with an "encounter," in which ship and whale are on a collision course, with the whale moving into the path of the oncoming ship at the surface at a swimming speed of 2 knots (a typical cruising speed for an adult right whale). The ship moves at constant speed and does not change course. The following events then take place:

- The whale detects the ship at a specified detection distance (DD)
- The whale initiates evasive action after a specified time delay (TD)
- The whale's evasive action is characterized by speed through water (WS), horizontal direction (DH), and dive angle (DV)
- If the resulting closest point of approach between ship and whale is below a specified threshold, the encounter results in a collision

We implement this model in Matlab and conduct repeated simulations for a range of parameters (see below) to generate the expected distributions of outcomes.

Data

Data on detection and response distance come from our review of observed encounters between right whales and vessels (primarily from observations taken during aerial surveys for right whales). The results of our review of 37 such encounters, observed primarily between 2001 and 2006 along the US east coast, are summarized in Figure 1 below.

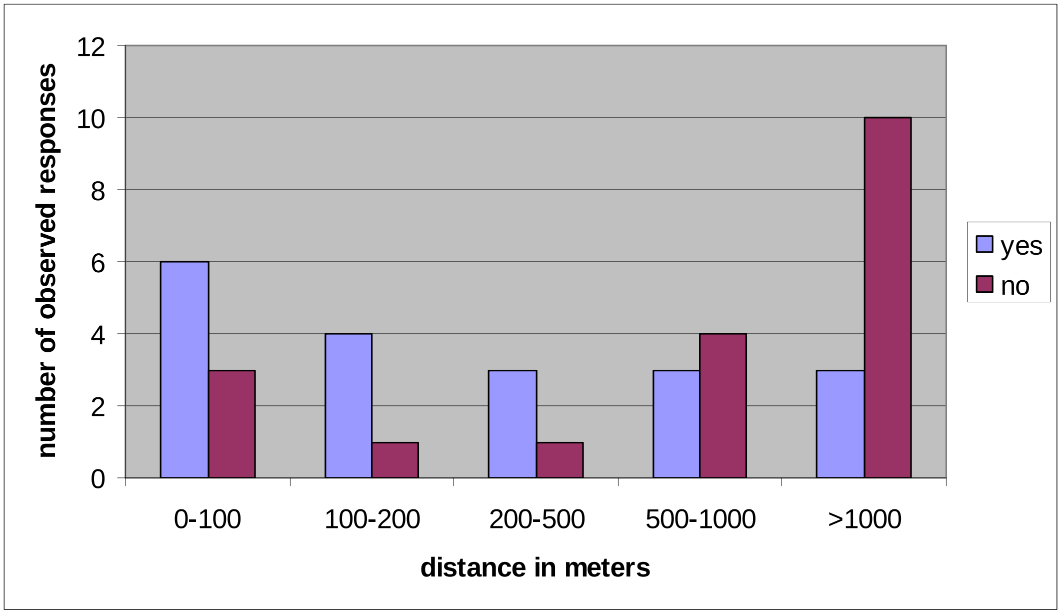

Figure 1: Observed response of Right Whales to presence of vessels as a function of distance (closest point of approach). Blue bars ("yes") indicate evasive response; red bars ("no") indicate no apparent response. Based on data analysis conducted by A. Knowlton and M. Brown.

The negative observations for close range encounters (0-100m) involved small recreational vessels. We conclude from this analysis that right whales usually do respond to encounters with commercial ships, and that they appear to initiate their response (and perhaps detect the ships) over a wide range of distances. Because evasive action initiated at distances above 500m is relatively infrequent, we model detection distance (DD) for our purposes as uniformly distributed over the interval [0, 500m].

The delay time between detection and evasive movement is based on the typical time interval between pre-dive blow and disappearance of flukes. We model delay time (TD) as uniformly distributed over the interval [5, 11 secs] based on an analysis of video clips of whale diving behavior conducted by A. Knowlton.

The whale's speed through the water during evasive action is based on the range of observed swimming speeds of right whales from two sources: data from right whales equipped with telemetry tagas (Nowacek *et al.* 2001, 2004) during feeding dives (data provided by Doug Nowacek), and observations of whales swimming at the surface measured with GPS on a nearby research boat (New England Aquarium unpublished data). We model whale speed (WS) as distributed over the interval [1, 7 knots] with slightly greater weight on the middle of the speed range than on the extremes.

The horizontal direction of the whale's evasive movement is assumed to reflect an effort by the whale to escape from the perceived threat, and is based, in part, on aerial observations of whale movement in the presence of vessels. We model this parameter as uniformly distributed over the interval [30, 90 degrees], representing the angle of the whale's horizontal movement with respect to the course of the vessel. We do not consider evasive movement at angles less than 30 degrees because that kind of behavior has not been observed, to the best of our knowledge.

Finally, the whale's dive angle during evasive movement is modeled as uniformly distributed over the interval [0, 80 degrees] with respect to the surface. This reflects an analysis of telemetry tag data (provided by Doug Nowacek) indicating the range of dive angles for right whales, as well as observation of whale movements in the presence of vessels.

Table 1 summarizes the parameters characterizing the whale's evasive behavior for the purposes of our modeling exercises.

range at which whale detects/reacts to vessel (DD)	0 – 500 meters
time delay between detection and evasive movement (TD)	5 – 11 seconds
whale's speed through water in evasive movement (WS)	1 – 7 knots
horizontal direction of evasive movement (DH)	30 – 90 degrees from course of vessel
vertical (dive) angle of evasive movement (DV)	0 – 80 degrees

Table 1: Characterization of whale evasive behavior

We conducted model runs of ship-whale encounters for several vessel types, as shown in Table 2. Recognizing that hydrodynamic forces along the hulls of vessels can draw nearby whales toward the ship, particularly along the aft part of the hull where the propellers are located, we add to the physical dimensions of the ship a "critical zone" of 5 or 10 m for conventional ships, 5 m for barges, and 3 m for fast catamarans. These adjustments reflect the findings of Knowlton *et al.* (1995, 1998) that under certain circumstances, negative pressure along the aft portion of a passing ship's hull sufficient to draw a whale into a collision can extend outward from the hull for up to 60 percent of the ship's beam. We consider the outcome of an encounter to be a ship strike if the closest point of approach brings the whale within that critical zone around the ship.

Vessel	**Beam (m)**	**Draft (m)**	**Typical operating speed (kts)**
Large conventional (large container ship)	30	12	20
Smaller conventional (bulk carrier)	20	8	15
Large barge	27	6	12
Small barge	18	3	12
Large high-speed catamaran	26	4	40

Table 2: Principal dimensions of vessels used in model runs

Results

Figure 2 summarizes the model results for all vessel types, using the assumptions about whale behavior spelled out above. Tug/barges operating at speeds between 10 and 15 knots generate strike fractions (the likelihood of a ship strike given a whale swimming into the path of the vessel) of about 30 percent. For conventional ships, the strike fraction rises more or less linearly from just above 30 percent at 10 knots to above 50 percent at speeds close to 25 knots. The strike fraction for large fast catamarans is similar, between 50 and 60 percent at speeds between 30 and 40 knots.

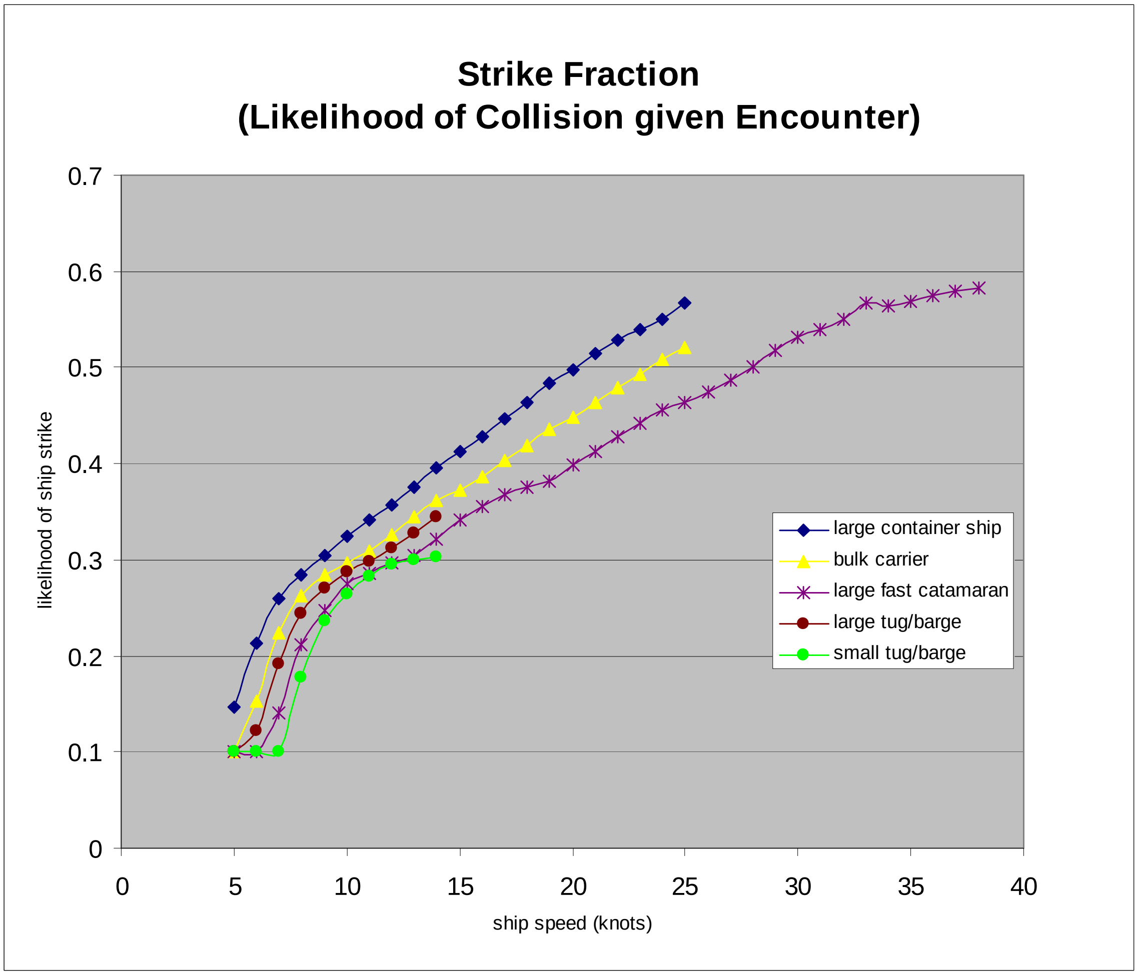

Figure 2: Strike fraction for different ships as a function of speed

Figure 3 illustrates the strike risk reduction attainable by imposing speed restrictions on conventional ships that normally travel at high speeds of 20 knots or more. The baseline risk for this purpose is the strike fraction shown in Figure 2 for speeds between 20 and 25 knots. By slowing these ships to 12 or 13 knots, the risk of ship strikes is reduced by about 30 percent. By slowing to 10 knots, the strike risk is reduced by 40 percent.

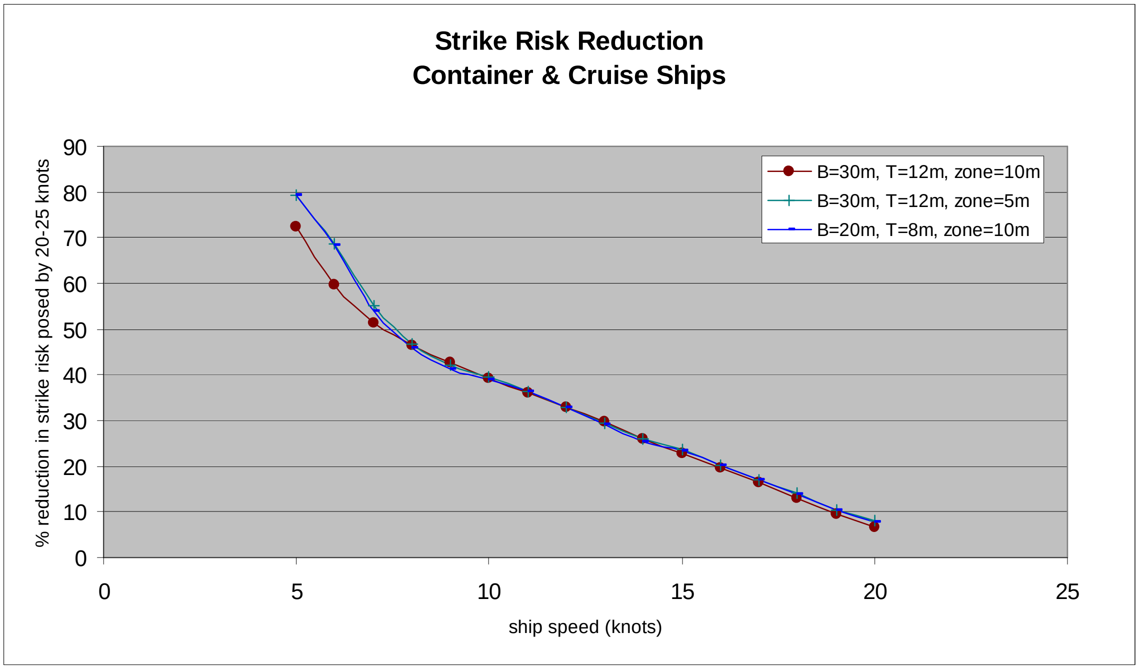

Figure 3: Strike risk reduction for fast conventional ships as a function of speed limit imposed

Perhaps the most difficult and controversial parameter in the whale response is the distance at which whales detect and react to approaching vessels. Recall that for the analysis described above, we assumed a detection distance uniformly distributed over [0, 500m]. To illustrate more explicitly the effect of detection distance on strike risk, we isolated this parameter in the model and generated the results shown in Figure 4.

These results suggest that for conventional ships, encounters are virtually certain to result in ship strikes at speeds in excess of 10 knots if the detection distance is 50m or less. When detection distance is around 100 m, there is no appreciable strike risk for ship speeds below 10 knots; the strike risk rises rapidly to between 50 and 80 percent at 15 knots, and exceeds 90 percent above 20 knots. For detection distance of 150 m, strike risk is negligible below 15 knots, and reaches 60 to 80 percent at 25 knots. At 200 m detection distance, strike risk begins at 20 knots and stays below 40 percent even at 25 knots. Detection distances of 250 m or above imply very low ship strike risk from conventional vessels.

A full assessment of the danger to whales from ships must take into account both the risk of collision and the likely severity of the resulting injury. Both of these factors are a function of ship speed. While our analysis in this report addresses the strike risk, other research is beginning to quantify the injury potential. Vanderlaan and Taggart (2007) model the probability of lethal and nonlethal injury to large whales struck by ships using historical records, focusing primarily on sharp trauma cases such as propeller blade cuts. They estimate that the probability of a lethal injury given a ship strike increases from 0.21 at ship speeds of 8.6 knots to 0.5 at 11.8 knots and 0.79 at 15 knots. Campbell-Malone (2007) and colleagues (Campbell-Malone *et al.* 2006) have examined histologic evidence and developed bio-mechanical models to better understand the consequences of blunt trauma injuries.

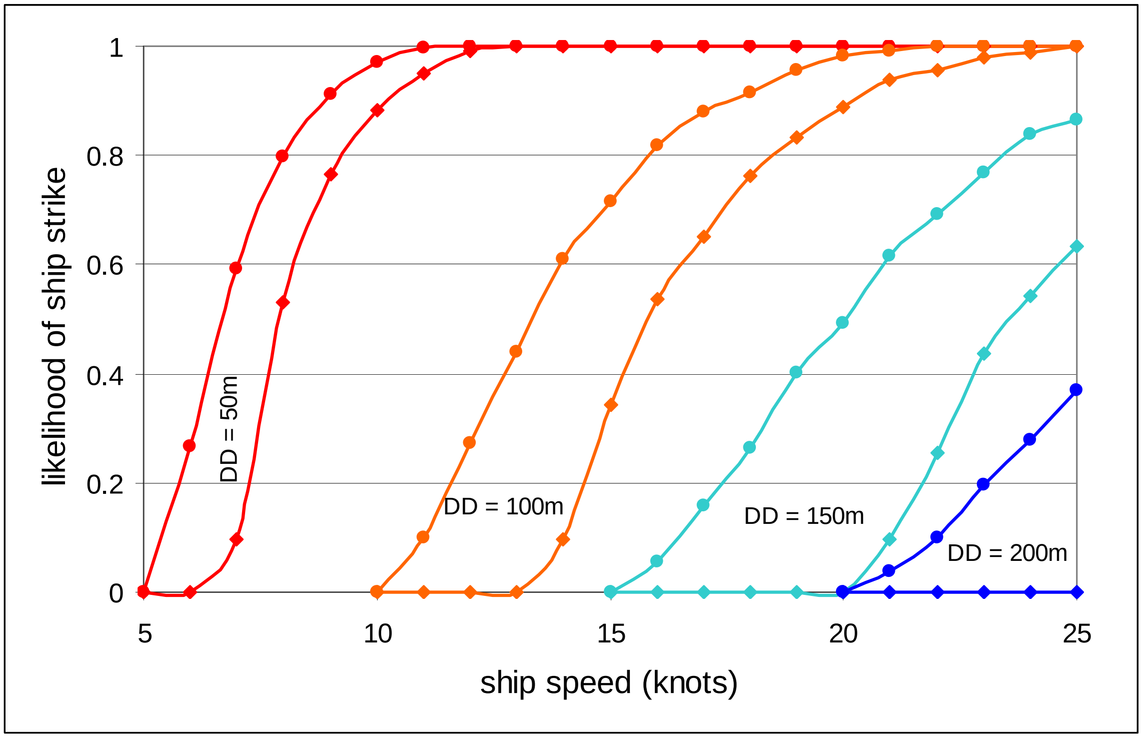

Figure 4: Strike risk for conventional ships as a function of detection distance (DD) and ship speed

Conclusions

Model results suggest that more than half of right whales located in or swimming into the path of an oncoming ship traveling at 15 knots or more are likely to be struck even when they do take evasive action. The model also suggests that the strike risk posed by a conventional ship moving at 20 to 25 knots can be reduced by 30 percent by slowing to 12 or 13 knots, and by 40 percent at 10 knots. Whales are likely to be largely safe from ship strike if the detect and react to oncoming vessels at a distance of 250 m or more. Strike risk is considerable if the detection distance drops below 100 m.

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