A note on the friction of different ropes in right whale (*Eubalaena glacialis*) baleen: an entanglement model

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ABSTRACT

Entanglement in fishing gear, particularly fixed trap, constitutes a significant source of North Atlantic right whale (*Eubalaena glacialis*) mortality. Entanglements may initiate with rope fouling baleen plates before snagging other appendages. Low friction between rope and baleen may minimise the risk of a sustained, progressive entanglement. The friction of eight different rope types against right whale baleen was examined by measuring the tension as each rope was pulled through two baleen plates held underwater. Polypropylene rope generated less friction with the baleen than all other fibres tested, including nylon, polyester, and commercial sinking line (a polypropylene/polyester blend). Thus, new commercial floating line (3-strand polypropylene) generates less friction than new commercial sinking line, both of which are commonly used in the fixed gear industry. Therefore, minimising rope friction should be one of the design parameters for whale-safe fixed fishing gear. Further study is required on the impact of rope aging, mouth closing and operator safety before recommendations can be made to industry.

KEYWORDS: FISHERIES; CONSERVATION; INCIDENTAL CAPTURE; NORTH ATLANTIC RIGHT WHALE

INTRODUCTION

A study of 54 known North Atlantic right whale (*Eubalaena glacialis*) deaths from 1970 to 2001 revealed that ship collisions were responsible for 35% of these deaths and 9% were the result of gear entanglement (Knowlton and Kraus, 2001; McKiernan *et al.*, 2002). More than 70% of the right whale population bears scars from entanglement, and the numbers of fatal and potentially fatal entanglements have increased significantly in the last few years (Knowlton *et al.*, 2001). Many whales that die from entanglement are extremely emaciated at the time of death: the carcass will sink if negatively buoyant. Since these carcasses often cannot be recovered, it appears likely that the impact of gear entanglements has been underestimated in the past (Knowlton and Kraus, 2001).

North Atlantic right whales filter feed by swimming with their mouth open, gathering large numbers of copepods as the water flows in passively. Right whale entanglements regularly involve the mouth, with fishing gear being entangled in the baleen. Kozuck *et al.* (2003) found that 74% (29/39 entanglement events which involved 35 individuals) involved the head/mouth region as the point of gear attachment (Figs 1 and 2), along with other body parts. A total of 54% (21/39 entanglement events) involved only the head/mouth region as the point of gear attachment. In the same study 8/15 dead or presumed dead right whales were entangled in the head/mouth region. Therefore, it seems reasonable to predict that using fishing gear with reduced friction against right whale baleen may help increase the rate of self disentanglement. This study was conducted to compare common types of line used in the commercial fishing industry. Eight ropes of various fibres and constructions were pulled through the baleen, and the resulting tension was measured. It was discovered that polypropylene generates the least friction with baleen.

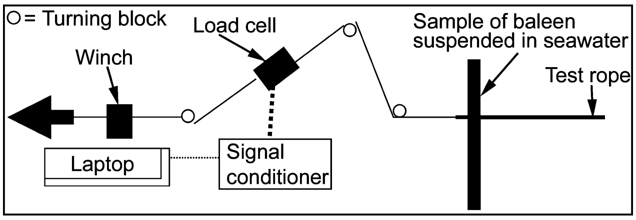

Fig. 1. Experimental design for pulling rope through right whale baleen suspended in sea water.

It has been predicted that preventing the deaths of two females per year may allow the right whale population to begin to recover (Fujiwara and Caswell, 2001). Gear modifications that prevent entanglements are critical for the survival of the species.

METHODS

Samples of baleen were removed during necropsy from three North Atlantic right whales, comprising New England Aquarium Catalogue Numbers 1014, 1504 and 1238 (Moore *et al.*, 2005). The samples, which contained blocks of 9 to 24 plates, were clamped between two timbers that were fixed to overlie a tank (Fig. 1). The gum line was situated at the underside of the timbers, which coincided with the surface of sea water filling the tank into which the baleen plates projected. The test line was pulled between two plates of baleen in the sample with a *Lewmar 44* 2-speed manual self-tailing winch via turning blocks. The same pair of plates was used for each sample. The order in which the rope types were tested was randomised for each baleen sample. Preliminary tests showed that friction was independent of

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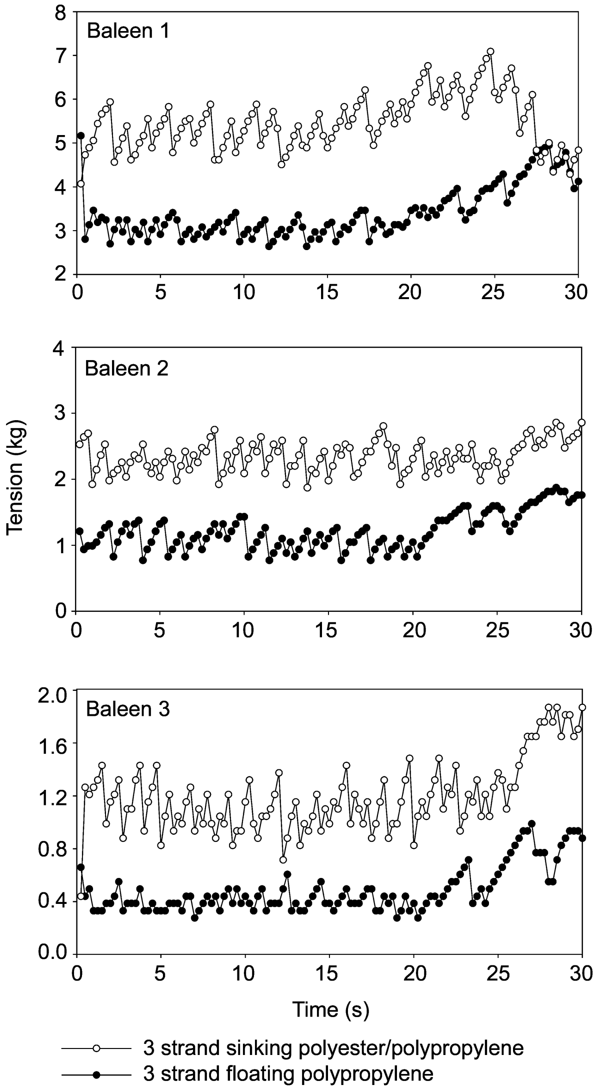

Fig. 2. Examples of tension records for two rope types pulled between three different samples of right whale baleen as examples of the raw data obtained.

the speed at which the rope was pulled, confirming that friction is independent of speed at low pulling velocities (Mclean and Nelson, 1952).

Eight different rope types were tested. All ropes had a diameter of 9.5mm (3/8 inch). Rope types were: (1) 3-strand polyester; (2) 3-strand nylon; (3) 3-strand polypropylene (commercial floating line); (4) 3-strand commercial sinking line (polypropylene and polyester blend); (5) braided polyester; (6) braided nylon; (7) hollow braid polypropylene; and (8) braided polypropylene. Test ropes were pulled through the baleen just below the gum line (40cm below the crown of baleen sample 1, 26.5cm below the crown of baleen sample 2, and 30cm below the crown of baleen sample 3). Three samples of each rope type were used, one for each sample of baleen. Rope samples were obtained from 3 different spools for all rope types except the 3-strand sinking line, 3-strand polyester, and hollow braid polypropylene. All ropes were manufactured by New England Ropes, New Bedford, Mass. (USA) except for the commercial sinking (Super Hyliner, Cape Fishermen's Supply, Chatham, USA) and floating (Wellington Puritan, Madison, USA) lines.

An MLP-100 load cell tensiometer (Transducer Techniques, Temecula, USA), measured the tension as the test rope passed through the baleen (see Fig. 1). The signal from the load cell was modified by a TMO-1 amplifier/conditioner module with optional ATM-1 enclosure and APD-12 AC Power Adaptor (Transducer Techniques), a domino-2 coprocessor (Micromint Inc., Lake Mary, USA), and an 8-channel multi-range A to D converter (Digi-Key Corporation, Thief River Falls, USA). The modified signal was recorded using software developed by Upper Cape Systems (East Falmouth, USA). This system generates an accuracy of 0.03% of the maximum capacity of the load cell (45kg capacity, 14g accuracy for this model: Transducer Techniques, product literature). The tension was measured four times every second during the test pull. The initial start up phase was then deleted from each pull data file. Tension, over a standard amount of time of each pull for each baleen sample, was then averaged in a series of comparisons.

To test whether rope types differed in the amount of friction generated, a randomised blocks design was utilised with rope type as the fixed factor and the three pieces of baleen as blocks. Four *a priori* contrasts tested whether friction differed between the two types of rope construction (3-strand versus braided) and whether friction differed between ropes of different fibre (polypropylene versus nylon, polypropylene versus polyester and polyester versus nylon). The per comparison error rate ($\propto$ = 0.0125) was set using the Bonferroni method. A Tukey's multiple comparison test was performed to determine whether the mean tension of 3-strand sinking line and hollow braided polypropylene line differed from the other rope types. Data were log transformed to homogenise the variances for the statistical tests.

RESULTS

For a given rope type and baleen sample, mean tension varied over time and between baleen samples, but the differences in tension between the rope types for a specific baleen sample were relatively consistent. Examples of the raw data plots obtained are shown in Fig. 2. The tension showed a phasic pattern as the rope went through successive cycles of sticking and releasing, producing a saw tooth tension plot. The difference in the mean tension of the two rope constructions, 3-strand and braided, was not significant (Table 1). Different rope fibres, however, resulted in some significantly different mean tensions. The mean tension of polypropylene line was significantly lower than that of nylon or polyester line (Table 1; Fig. 3), whilst there was no significant difference between tensions of polyester and nylon.

Table 1

A priori contrast results comparing mean tensions of different rope constructions and fibre types.

Test	Df	SS	*F*	*P*
3-strand vs. braided	1	0.019	0.661	0.4297
Polypropylene vs. nylon	1	0.708	24.168	0.0002*
Polypropylene vs. polyester	1	0.729	24.894	0.0002*
Polyester vs. nylon	1	0.000	0.0326	0.8592

*Statistically significant (P <0.01).

Commercial sinking line had the highest mean tension of all the lines tested, but mean tension of this line was only significantly different from those of the three different polypropylene lines tested, Fig. 4). Mean tension did not differ significantly between the three polypropylene lines.

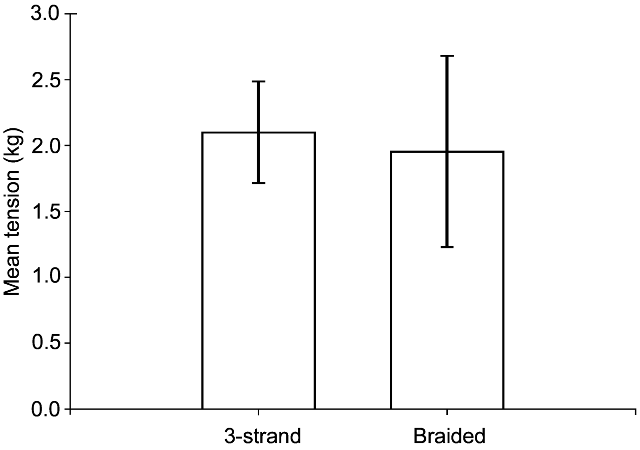

Fig. 3. Mean tension and ±1 standard deviation (n=3) for the two types of rope construction. The mean was calculated from the average of the three rope materials, nylon, polyester and polypropylene.

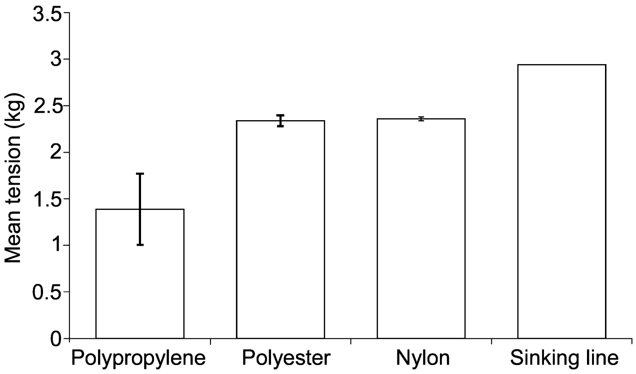

Fig. 4. Mean tension and 1 standard deviation (n=2) for the 4 rope materials. The mean was calculated from the average of the braided and 3 strand values. There is no error bar for sinking line because no braided line was available for this rope type.

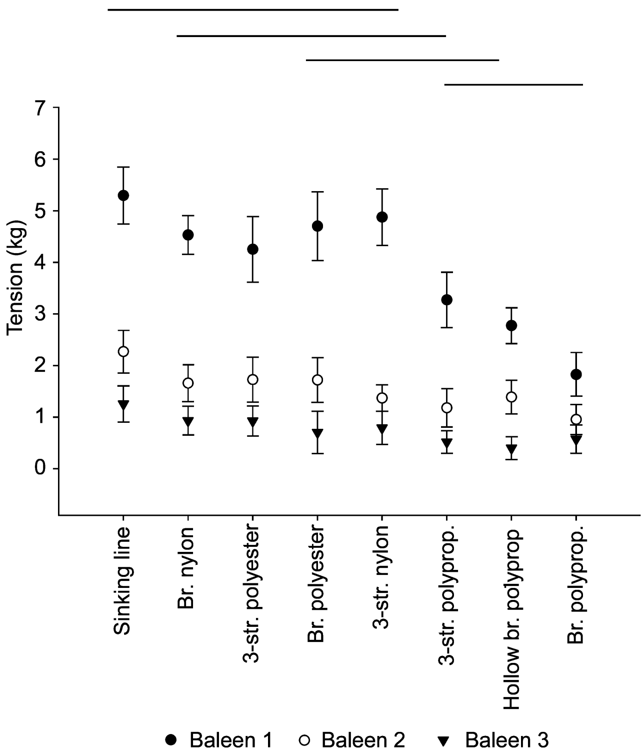

Fig. 5. Mean tension and 1 standard deviation for each rope type and baleen sample tested. The mean was calculated by taking the average of the tension values over a standard portion of the test run. Horizontal lines above the graph connect means of rope types that are not statistically significant. (Br.=Braided, Str.=Stranded).

DISCUSSION

This study was designed to compare the behaviour of different kinds of rope in right whale baleen in order to develop a better understanding of rope-baleen interactions during gear entanglement with the mouth. Of all the rope fibres examined, polypropylene line (commercial floating line) generated the least friction with right whale baleen.

The fixed trap industries generally prefer to use floating ground-line between traps because it is less expensive, avoids chafing on rocky substrates, and allows fishermen to retrieve trap gear more easily when buoy lines are severed (McKiernan *et al.*, 2002). However, the use of floating lines for ground-line has been shown to produce arcs of line between traps extending 3-6m above the substrate. These arcs of line in the water column increase the risk of entanglement. For this reason, regulations exist to encourage the use of sinking line in parts of the United States east coast lobster industry.

Commercial sinking line is typically composed of about 60-65% polyester and 35-40% polypropylene fibres (pers. comm. with Hy-Liner Rope Inc., Rockland, Maine, USA). The polyester is required to counter the buoyancy of polypropylene so the line will sink. Polypropylene is about a third of the cost of polyester, so manufacturers generally use as much polypropylene as possible.

Given the regular appearance of mud on their heads (unpublished data), right whales must sometimes feed on and in bottom mud. If entanglements do occur there, this may be fishery dependent – lobster gear is typically set on harder substrates. The results presented in this paper suggest value in the development of a sinking ground-line that has less friction with right whale baleen. A relatively low-friction sinking line could be made by creating a polypropylene sheath around the line, while maintaining the property of negative buoyancy. Weighting polypropylene line with lead to make it sink is also a possible alternative.

The relative tensions on baleen of the different rope fibres do not relate directly to the coefficients of friction reported by Samson Rope Technologies (Table 2). A coefficient of friction is defined as the ratio of force of friction to the normal (perpendicular) force. These values are dependent on the surface that it is being pulled against. Coefficients of friction for one rope type can change greatly when measured against different surfaces and in wet versus dry conditions (Brown, 1977). Therefore, rope-baleen tensions cannot be predicted by established friction coefficients. Furthermore, this study focused only on new rope samples. Polypropylene in particular undergoes significant changes in surface properties as it ages. Future work should focus on comparing the friction generated by rope between samples of different age. In addition further studies should also compare the operational practicalities of slippery rope in the field setting, and extend to include the behaviour of different rope types on whale skin, as any rope that is significantly entangled in baleen will also be rubbing over one or more skin covered body parts, especially the gum, axilla and caudal peduncle. When the mouth is closed, a significant increase in friction is caused by the bite of the lower lip against the gum; however this is reversible, as right whales swim for substantial periods with their mouths open when filter feeding. It is also important to try to determine whether low friction rope has a positive or negative effect on other types of entanglements (e.g. flippers, tail).

Table 2

Coefficient of friction vs. mean tension for selected commercial ropes.

Rope fibre	Coefficient of friction	Mean tension (lbs)
Nylon	0.89	5.244
Polyester	0.33	5.196
Polypropylene	0.37	3.084

Finally, before any significant reduction in rope friction is attempted in an industrial setting, the impact of such a reduction on the safety of operators will also need to be evaluated.

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