NOTE TO SOUTH ATLANTIC FISHERIES MANAGEMENT COUNCIL-Feb 23, 2015

Below is a paper recently submitted for peer-review. We have been asked to provide it to you to assist in your discussions regarding the black sea bass fishery (we request that it not be circulated beyond the Council at this time). To that end, we felt it important to state what this paper does and does not tell us about entanglement of neonate right whales in the right whale calving ground. As the paper notes, for right whales especially, it appears that breaking strengths of 1700 lbs or less would benefit adults and likely juveniles of 1 yo or more as well as other large whale species. Our dataset did not include any gear removed from right whale calves except for one that was about to turn 1 year old. However right whale neonates have a much smaller body size and weight than a 1 yo whale because of rapid growth rate during their first year. Therefore we have no information about the breaking strength neonates on the SEUS calving ground would be able to handle. Neonates also will have no prior experience with trying to escape from entangling gear and will be at a vulnerable time in their lives when they are just trying to figure out how to nurse and exist in the world. In our study, we recorded two minke whales found dead in ropes of 650lb breaking strength, and these animals were much larger than neonates. Therefore, we feel that even 600 lbs may be too high for a neonate and there may be no safe strength for this age group of right whales. While this is mentioned in the paper, we wanted to reiterate it here as well. We believe the use of reduced breaking strength ropes in the calving ground may not provide the necessary protection for neonates that the existing closure presently does.

If reduced breaking strength ropes are to be considered in the calving ground, we believe there needs to be research conducted in advance to determine the strains imposed on this gear during hauling, setting, and towing (this can help determine the minimum breaking strength that would be feasible for fishing) and to investigate this question some more using a whale entanglement simulator program developed by the NEAq and Bellequant Engineering, to provide insights into the likely outcomes of these events for whales of given sizes and ropes with variable breaking strengths.

IMPLICATIONS OF FISHING ROPE STRENGTH ON THE SEVERITY OF LARGE WHALE ENTANGLEMENTS

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ABSTRACT

Entanglement in fixed fishing gear is a conservation concern for large whales worldwide, including in the United States where deaths of North Atlantic right and humpback whales have exceeded management limits for decades. We examined fishing gear removed from live and dead entangled whales along the US East Coast and the Canadian Maritimes from 1994-2009 to investigate rope polymer type, breaking strength, and diameter in relation to whale species, age, and injury severity. For the 132 retrieved ropes from 70 cases, average tested breaking strength was 2,616 lbs (SD 1,863; range 180-8910 lbs), which is 26% lower than strength at manufacture (mean 3,530, SD 2,224; range 650-12,000 lbs). Median rope diameter was 3/8 inch. Right and humpback whales were found in ropes with significantly stronger breaking strengths at manufacture than minke whales (4,338, 3,850 and 2,353 mean lbs, respectively). Adult right whales were found in stronger ropes (mean 7,664 lbs) than juvenile right whales (mean 3,446 lbs) and all humpback whale age classes (mean 3,906 lbs). For right whales, injuries have become more severe over the past three decades, possibly due to changes in rope manufacturing in the mid 1990's that resulted in stronger ropes at the same diameter. Our results suggest that broad adoption of ropes with breaking strengths of 1,700 lbs or less could reduce the number of life-threatening entanglements for large whales by at least 72%, and still be strong enough to withstand the routine forces involved in most fishing operations. A reduction of this magnitude would achieve nearly all of the mitigation legally required for US stocks of North Atlantic right and humpback whales. Reduced breaking strength ropes should be developed and tested to determine the feasibility of its use in a variety of fisheries.

INTRODUCTION

Serious injury and mortality from entanglement in fixed fishing gear is a chronic problem facing large whale populations worldwide (Read 2008, International Whaling Commission 2010). Entanglements can lead to near-instantaneous death through drowning (Moore et al. 2013), delayed death from impaired feeding, severe injuries, increased energetic demands when gear remains attached for periods of time (Cassoff et al. 2011; Moore et al. 2013), or a stress response that may impact health and fecundity even after the gear is no longer attached (Pettis et al. 2005; Knowlton et al. 2012). The frequency and severity of entanglements have been well studied in endangered North Atlantic right whales (RW, *Eubalaena glacialis*) and humpback whales (HW, *Megaptera novaeangliae*) along the east coast of North America. These species encounter gear at minimum annual frequencies averaging 12% to 16% of the population (Robbins 2012; Knowlton et al. 2012). For RW, 83% of the population shows scarring from conflicts with fishing gear with a significantly increasing rate of serious entanglements detected over a 30 year period (Knowlton et al., 2012). Negative effects of entanglement on survival have been documented in both species (Knowlton et al., 2012; J. Robbins, pers. comm.), and observed deaths have exceeded the Potential Biological Removal (PBR) levels defined by the U.S. National Marine Fisheries Service (Wade 1998) for nearly two decades (Waring et al. 2014; van der Hoop et al. 2013; Pace et al. 2014). Federal law requires substantial reduction in the number of human-caused deaths of both species, including from entanglement.

In the United States, RW, HW, and FW are protected under the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973, and in Canada, RW are considered Endangered under the Species At Risk Act of 2003. As a result of these laws, considerable effort has been directed at documenting entanglement levels in these species, disentangling whales in U.S. and Canadian waters, and collecting and assessing gear retrieved from entangled whales. Ropes from a wide range of fisheries have been implicated in entanglements, with a majority that could be identified coming from pot/trap and gillnet fisheries (Johnson et al. 2005). To reduce entanglements, management efforts in U.S. waters have included inserting weak links in ropes at certain points, mandating the use of sinking groundlines between lobster traps, and a closure to gillnets in the right whale calving ground off the southeast U.S. (see Appendix S1 in van der Hoop 2013). The efficacy of these types of mitigation efforts remain unknown, partly because 1) ropes are not marked adequately to identify fisheries or locations, 2) how and where entanglements occur is unknown, and 3) the link between gear characteristics and outcome for the whale is poorly understood. Nevertheless, none of these management efforts have reduced serious and lethal entanglements of large whales (Knowlton et al. 2012, van der Hoop 2013; Pace et al. 2014; New England Aquarium and Center for Coastal Studies, unpublished data)

Studies of retrieved gear samples have the potential to offer insights into the causes of entanglement, as well as potential mitigating strategies. Previous studies of entangling gear have focused on identifying the gear type and components involved in entanglement events (Johnson et al. 2005). Here, we examined additional characteristics of rope retrieved from entanglement events, the configuration of those entanglements, and the resulting injuries to individual whales. The specific objectives of this study were to: 1) analyze the properties of rope removed from entangled whales, 2) examine rope characteristics in relation to whale species, age and injury severity, and 3) identify temporal trends in RW entanglement configurations and injury severity from 1980 to 2009 in relation to changes in rope manufacturing practices.

METHODS

The Atlantic Large Whale Disentanglement Network (ALWDN) recovered most of the gear samples used in this study, which were removed from free-swimming entangled whales under the authority of the U.S. National Marine Fisheries Service (NMFS) and Canada's Department of Fisheries and Oceans (DFO). They included RW, HW and two finback whales (FW, *Balaenoptera physalis*) from Florida to the Bay of Fundy. These samples were augmented with gear gathered by stranding networks from entangled carcasses (including minke whales, MW, *Balaenoptera acuturostrata*) on the beach or at sea. All retrieved gear was archived by NMFS. Data about entanglement configuration was obtained from photographic and written records of the original entanglement event, disentanglement efforts, and stranding records archived at the New England Aquarium (NEAq) for RW, Center for Coastal Studies (CCS; Provincetown, MA) for HW and RW, and by NMFS for MW and FW. Entangled individuals were identified using photo-identification catalogs maintained by NEAq (for RW; http://rwcatalog.neaq.org) or CCS (for HW). Photo-identification data were used to provide life history information of individual RW and HW, and to further describe the severity of entanglement events.

Analysis of ropes

Gear collected from 70 large whale entanglements from 1994 to 2010 included 132 different ropes. We conducted analyses on samples of the gear to assess the following rope characteristics:

- Diameter (exact measurements and the nearest nominal fraction)
- Material and fiber type (as determined from visual inspection)
- Assessment of rope condition - five categories: very good, good, fair, poor, very poor (as determined from visual and tactile inspection by experienced analyst HM)
- Estimated breaking strength - Determined from one of three methods: 1) testing up to three 10-foot segments of whole rope pulled to breaking strength at a laboratory experienced in fiber rope testing; 2) testing individual yarns using textile testing equipment with rope strength extrapolated using historical procedures based on rope construction; 3) adjusted from a new rope of identical type and diameter based on condition. Adjustment levels given were 100, 80, 60, 40, and 20% of new rope strength based on the five categories of very good to very poor, respectively.
- New rope strength for same type and diameter rope (a representative value was selected by HM for the new strengths based on research into 12 sources: 11 rope-makers' published data and Cordage Institute standards).

Additional rope characteristics were measured but not analyzed for this study. Complete data and detailed descriptions of methodologies used for rope analyses are provided in the Appendix S1 and S2.

Analysis of entangled whales

We combined available life history information, the configuration of gear on the animal, an assessment of injury severity, data on the rope removed, and information from the NMFS Fishery Interaction Gear Analysis reports (see example in Appendix S3; see www.bycatch.org for RW case studies). In many cases, entanglement configuration and injury severity were reconstructed only from event photographs that limited the detail of some assessments, particularly for HW as key body parts could not be consistently observed. Less information was typically available for entanglements of FW and MW.

Gear diameter and breaking strength at manufacture (i.e. “new”) were analyzed in relation to whale species, age (or age class), and the severity of entanglement configuration and associated injuries (see below). In some cases entanglements involved more than one rope type, indicating either that multiple components of an individual fisherman’s gear were involved or that the whale was entangled in gear from different sets. In those cases, we used the rope sample with the strongest strength at manufacture for the analyses and no attempt was made to tie specific rope samples to injuries at individual body areas, since entanglements act upon whales in complex ways. Descriptive statistics (mean, median, quartile, minimum, maximum and range) were calculated for breaking strength of the retrieved ropes by species, by injury severity, and by age or age class. For RW, all individuals were previously catalogued individuals, and the year of birth was known in most cases. Statistical differences in the average breaking strength of gear among groups were tested with a one tailed Student’s t-test. The objective was to test the null hypotheses that 1) whale age (a proxy for size, which could not be reliably measured) would have no correlation with rope strength; 2) injury severity was unrelated to rope strength; and 3) the severity of RW entanglement configuration and injuries would not change over time.

<u>Age</u>

Age was determined for RW based on photographic histories using a protocol developed by Hamilton et al. (1998). The age categories used in this study were calf/ juvenile (0-2 years), younger juvenile (3-5 years), older juvenile (6-8 years), adult (9 or more years), unknown age (birth year unknown and sighting history less than 8 years).

HW were allocated to age classes based on known age, photographic sighting history, length, or apparent size as estimated by observers (in the absence of other information). Age classes were as follows: juvenile (less than five years and/or reported to be of juvenile size), adult (no less than five years and/or reported to be of adult size), and unknown (unknown age and physical size was not noted).

For MW and FW, age and age class were not determined.

<u>Injury severity</u>

The severity of entanglement injuries was assessed for all RW and HW cases in which gear was retrieved and analyzed. Injury severity was categorized as follows: minor injuries were superficial skin abrasions, moderate injuries were extensive skin abrasions or cuts that extended into the blubber, and severe injuries were cuts estimated to be greater than 8 cm in depth or determined to extend into muscle or bone (detailed criteria given in Appendix S4). For an injury to be attributed to entanglement, evidence of the rope having “wrapped” on the corresponding region of the body was required. Five body regions were assessed for injuries when adequately documented: head/rostrum, mouth, body, flippers, and tail. However, photographs of all body parts in contact with fishing gear were not always available. When a clear assessment of the injuries could not be adequately made, the case was listed as “Unknown”.

Entanglement duration was also estimated for the RW and HW cases to better clarify injury severity results. Minimum duration was the time between the first sighting of entanglement and the date that the gear was retrieved. Maximum duration represents the longest time the whale could have been carrying the gear based on the last sighting without gear, or gear set/loss information provided by NMFS. When no bounding information was available, the minimum duration was assumed to be one day and the maximum duration was considered unknown. We then identified cases that were known to be short-term (maximum duration <30 days) or long-term (minimum duration >90 days).

Entanglement injury severity and configuration risk in right whales over time

Knowlton et al. (2012) showed that the proportion of annually sighted RW with attached gear or severe injuries had increased over a 30 year time period. To further assess when the changes in the rate of entanglements resulting in moderate/severe injuries occurred, we performed a binary logistic regression to test the null hypothesis of no change in probability over time ($\beta 1 = 0$). We then used an incremental approach to build the dataset by each additional year for the logistic model to identify years in which there was a significant variation in the probability of moderate/severe entanglements.

For this analysis, RW injury severity was assessed for all known entanglement events, for a total of 1,032 unique entanglement interactions from 1980-2009 (Knowlton et al. 2012). Injury severity for these cases was conducted as described above for cases with associated rope analysis. We also evaluated changes in the entanglement configuration risk over three decades. Configuration risk was coded as high or low (Appendix S4). High risk cases were those in which the whale had one or more of the following: one tight wrap, multiple contact points with the gear (attachment points: rostrum/mouth, flipper, body, or tail), trailing gear more than one body length, or which appeared to significantly impair or prevent movement. High risk cases were considered to be potentially life-threatening. Low risk cases were those involving no tight wraps, only one attachment point, gear trailing less than one body length, and no heavy gear attached and were not considered life-threatening.

RESULTS

Entangling rope characteristics

Rope specimens (n=132) retrieved from 70 entangled large whales (30 RW, 30 HW, 8 MW and 2 FW) were found to consist of 8 different materials (Table 1). The ropes documented comprised the full range of diameters used in pot and gillnet fishing in the study area, and most (71%) measured 5/16, 3/8, or 7/16 in, diameters commonly used in lobster fishing off the northeast coast of the United States (McCarron and Tetrault 2012). Fifty three percent (n = 37) of the whales with retrieved gear had more than one rope recovered. On average, there were 1.83 ropes analyzed per entangled individual, ranging as high as six ropes for one individual. When only the strongest rope in each case was tallied, the percentage of ropes in the 5/16, 3/8, and 7/16 diameters dropped from 71% to 62% of all the cases with the remainder of the strongest ropes in the higher diameter range (Table 1).

For rope condition, 70% were categorized as Good to Very Good with 14% as Fair and 16% as Poor or Very Poor. Of the ropes coded as Poor or Very Poor condition, most consisted of polypropylene or a polypropylene blend whereas the other condition levels had a broader variety of rope polymers. Rope diameters ranged from 0.177 in (sold as “3/16 in” commercially) to 0.933 in (“1 in”), and breaking strengths at manufacture ranged from 650 lbs to 12,000 lbs depending on the polymer and diameter (average 3,530, SD 2,224, median 2,600; Table 2). The estimated breaking strengths of ropes recovered from entangled whales ranged from 180 lbs to 8,910 lbs (average 2,616 lbs, SD 1,863, median 2,000; Table 2) or 26% lower than strength at manufacture.

Effects of rope characteristics on entanglement

<u>By species</u>

RW were found in ropes of higher breaking strengths than MW (t (24) = 3.04, p = 0.002), as were HW vs. MW (t (25) = 2.26, p = 0.016), but no significant difference was found between RW and HW (t (58) = 0.722, p = 0.237; Fig. 1, 2a). The average new rope breaking strength for 30 RW cases was 4,338 lbs (range: 1,700-11,500 lbs), for 30 HW cases, 3,850 lbs (range: 1,700-12,000 lbs), and for eight MW cases, 2,353 (range: 650-3,780 lbs). For the two FW cases, the new rope breaking strengths were 2,500 and 7,000 lbs.

All of the MW were found dead in the gear and likely had been anchored (i.e., unable to part the gear in order to become free-swimming). HW were found anchored in the gear in 33% (n = 9) of the cases whereas only one RW (3.3%) was anchored and subsequently drowned. The anchored RW was found in the strongest gear retrieved for that species (11,500 lbs), but breaking strength did not explain why some HW were anchored in gear (3013.3 average lbs) and others were not (4182.2 average lbs) however the sample size was small (n = 9). Both FW were free swimming.

<u>By age</u>

Twenty of the 30 RW cases (67%) involved calves and juveniles from 0-8 years old; seven were adults (23%) and two (7%) involved unknown age animals. Adults were found in significantly higher breaking strengths than all juveniles ($t(8) = 4.26$, $p = 0.001$; Fig. 2b, 3). The case with the highest breaking strength (11,500 lbs) involved a >19 year-old male (#1238) that drowned in the gear (Cassoff et al. 2011).

For HW, 63% (n=19) of the cases in this study involved known or suspected juveniles. Although an adult was entangled in the gear with the highest breaking strength measured (12,000 lbs), both juveniles and adults were distributed across the range of new rope strengths (Fig. 3) and the average breaking strength did not differ significantly among age classes ($t(9) = 0.576$, $p = 0.289$; Fig. 2c). When age class and species were taken together, the average breaking strength for adult HW was significantly lower than adult RW ($t(11) = 1.80$, $p = 0.026$; Fig. 2b, c) whereas a comparison between juveniles of the two species was not significant ($t(32) = 0.319$, $p = 0.376$).

<u>On entanglement injury severity</u>

Entanglement injury severity for 30 cases involving 28 individual RW (one whale #2212 was entangled three separate times) was predominately severe (50%, n = 15) with 11 moderate cases (37%) and four minor cases (13%; Fig. 3). This was the only species in this study with entanglements that were confirmed to exceed 90 days in duration (n=8, range: 100-573 days), and all long-term events involved moderate or high severity injuries. Although for RW there appears to be an increasing trend in breaking strengths versus severity (Fig. 2d), these differences were only significant when comparing minor to severe injury cases ($t\ (16) = 2.155$, $p = 0.02$).

When entanglement injury severity could be reliably assessed for HW cases with available gear samples (n=20), the injuries were most frequently minor (55%, n=11), versus moderate (15%, n=3) or severe (30%, n=6). In 10 additional cases, the severity of the injuries could not be reliably assessed on the basis of available documentation. One-third (n=10) of HW cases were confirmed short-duration events (<30 days) and none were known to be long-duration. The short-duration cases were of whales disentangled within 1 - 18 days and exhibited only minor to moderate injuries. For the 20 cases with complete information, there were no significant differences in average rope strength for entanglements resulting in minor injuries versus those resulting in moderate injuries ($t(2) = -0.533$, $p = 0.324$) or severe ones ($t(5) = 0.999$, $p = 0.182$; Fig. 2e).

<u>Entanglement injury severity and configuration risk in right whales over time</u>

An overall positive slope parameter ($\beta 1 = 0.046$) indicated an increasing rate of moderate/severe entanglement injury cases over time ($\chi 2 = 18.467$, $p < 0.001$). Slope parameters were variable over earlier years of the study period, but increases in the rate of moderate/severe entanglement injuries occurred with each year from 1997 onward ($\beta 1 = 0.012$, $p = 0.65$) and exhibited statistically significant trends from 2000 onward ($\beta 1 = 0.045$, $p = 0.04$; Fig. 4).

Configuration risk was assessed for a total of 73 entangled RW from 1980-2009 (Fig. 4). During the 1980's and early 1990's entanglements resulting in attached gear were infrequent and typically low risk. Beginning in 1993, the number of annual entanglements began to increase and risk become high for the majority of cases documented through 2009.

DISCUSSION

This is the first study in which the ropes retrieved from whales were specifically investigated to determine how breaking strength influences entanglement outcome. Because we rarely know how the gear was configured when the entanglement occurred, or how the whale first encountered the gear, we do not know whether the rope(s) recovered was representative of the given gear set that caused the entanglement, or if it represented the specific rope in which the whale initially became entangled. However, our analysis focused on the strongest rope likely involved in each case and we have no reason to believe that our gear sampling across cases was biased in this regard.

In addition, we did not know the average breaking strength of the sampled rope at the time it became entangled on the whale. At the moment of entanglement, the rope strength was somewhere between the new and estimated strength. Yet, in many of the cases, the whales had carried the gear for extended periods, or the retrieved ropes had been stored for several years before analysis. Therefore, we assessed both new and estimated breaking strengths (Fig. 1), and reached the same conclusions. However, we believe the new breaking strength is the most useful metric for our study, as most of the ropes (70%) were in either good or very good condition, and would have been closer to the newer value at the time of entanglement. Furthermore, metrics based on the strength of gear at manufacture are easier to incorporate into future mitigation and monitoring efforts.

Our first hypothesis, that injury severity was unrelated to rope strength, was rejected for RW, as it was significant for minor versus severe entanglement injuries. For HW, an increasing trend in breaking strength versus severity was not significant. These findings may be confounded by several factors. When an entanglement was first detected, it was often not known how long that whale had been entangled and at what point the injury reached the state at which it was ultimately observed. Injury severity can increase over the duration of the entanglement due to a variety of factors, including infection, the amount of drag, and/or if the whale grows into constricting gear. Conversely, disentanglement can prevent further injury that might have occurred had the gear remained attached. For example, the greater injury severity in RW versus HW cases in this study may be partially explained by their longer entanglement durations. This, in turn, is related to a number of factors not explored in this study, including differences in reporting and disentanglement success rates for the two species.

Our second hypothesis, that whale species or age (as proxy for size) would have no correlation with rope strength was rejected in several tests. When three species were compared, MW, the smallest species, were found in significantly lower breaking strength ropes than both HW and RW. When HW and RW were compared by age groupings, RW adults were found in significantly stronger ropes than all juvenile RW as well as both juvenile and adult HW groups, a species with less girth and strength than RW. The RW found in the strongest gear for that species (#1238 in 11,500 lb breaking strength rope) drowned during the entanglement (Cassoff et al. 2011). Further, 0-5 yo RW were found in rope strengths from 1,700 to 4,100 lbs whereas adult RW were found in rope strengths of 4,500 to 11,500 lbs, and 6-8 yo fell into both ranges. This notable difference in ranges between adults and younger juvenile RW suggest that either younger juveniles somehow evade entanglement in stronger ropes or that they may be more likely to die in stronger gear and go undetected. This latter scenario is the most plausible given the fact that some whales (including all the MW in this study) were found dead in the heavier gear. In addition, HWs in this study were more frequently anchored in the gear than RW, another possible indicator of strength differences. And lastly, the fact that no adult RW were found in ropes below 4,500 lb breaking strengths suggests they break through the weaker gear before getting involved in a life threatening entanglement.

Our third hypothesis that the configuration risk of RW entanglements and associated injuries would not change over time was rejected in both cases. Injury severity at moderate and severe levels showed a positive slope in 1997 and onward, with significant changes beginning in 2000 through the subsequent years covered under this study. The configuration risk data suggests that configuration risk increased starting in the mid 1990's, and from 1997 to 2009, high risk configurations represented the vast majority of RW entanglement cases. Thus, all three null hypotheses were rejected partially or fully, indicating that breaking strength played a critical role in the outcome of whale entanglements.

Although retrieved ropes were only available for a 13-year period, information on rope manufacturing changes over many decades provided information that might explain these temporal trends. In the early 1950s, fishing rope construction shifted from natural fibers (manila and sisal) to synthetic fibers (primarily polypropylene) that were stronger and resistant to rot. In 1992, the development of co-extrusion (aka co-polymer) methods allowed for the blending of different plastic resins to produce stronger and more abrasion-resistant floating ropes (McKenna et al. 2004). A co-extruded rope made of a combination of polypropylene and high-density polyethylene is often referred to by one of the brand names, *Polysteel*, and is now commonly used for fishing. Other developments included the manufacture of sinking ropes utilizing a blend of polyester fiber (PET) with either polypropylene or *Polysteel*, which had breaking strengths similar to the all-*Polysteel* ropes (McKenna et al. 2004).

Just prior to the rope manufacturing changes in the 1990's were changes in the manufacture of lobster traps, one type of fixed fishing gear that has been known to entangle whales. During the late 1970's and early 1980's, wooden traps were replaced with wire traps, and as one trap manufacturer noted: “Once they [wire traps] caught on it changed everything, revolutionized the fishery. It allowed fishermen to fish large gangs of gear, in some cases year round, and the wire traps were found to fish better.” (Fishermen’s Voice, June 2011, Vol 16). The combination of wire traps and the dramatic strengthening of ropes resulted in the ability to fish more and heavier gear in deeper waters and in areas offshore. It seems likely that these gear changes have led to more high risk entanglement configurations and the increased frequencies of moderate and severe injuries for RW detected from the mid 1990’s onward.

This is the first evidence-based analysis that supports a modification to fishing gear. Past regulatory changes for RW and HWs were based on intuition, and were never subjected to experimental evaluation before or after implementation. Here we present evidence indicating that reduced breaking strength (RBS) ropes of 1,700 lb or less, could make a major contribution to large whale entanglement mitigation. Based on the limited frequency of whales found in tested rope strengths below 1700lbs, implementation of RBS ropes could reduce the probability of mortality and suffering by at least 72% and potentially bring entanglement related whale kills down to legally mandated levels.

In the U.S., PBR for RW is set at 0.9 whales per year. From 2007-2011, entanglement mortality and serious injuries averaged 3.25 whales annually (Waring et al. 2014). For HW, PBR is 2.7 whales but annual mortalities have averaged 9.95 whales for the same timeframe (Waring et al. 2014). For both species, entanglement mortalities have greatly exceeded the allowable levels. If the broad usage of RBS ropes resulted in the reduction of mortalities and serious injuries of large whales by at least 72%, this could reduce annual kills of RW to 0.91 whales and HW to 2.79 whales, both close to the PBR levels set for both species.

The use of RBS ropes would not reduce the number of encounters between whales and gear and may not prevent lethal entanglements in some habitats such as the RW calving grounds where neonates will have even less strength than a MW (found in the lowest breaking strengths of only 650 lb). Further, the benefits to other protected species, such as sea turtles, would likely be minimal.

If RBS ropes are to be considered, they need to be practical for fishing. Load cell studies in the Gulf of Maine have shown nearshore lobster trawl hauling loads to be around 500-700 lbs, except in one instance where it was recorded at 1100 lbs (Salvador and Kenney, 2002). By contrast, these forces may reach 2,800 lbs during hauling of very heavy offshore gear (a 48-trap trawl in 185fms) (Salvador et al., 2003). The highest load cell measurement of gillnet gear from the Bay of Fundy was 700 lbs during setting and 550 lbs when hauling, from gear set in 50 fathoms with an 80 lb grapple and 85 lb kedge type anchors. When towed, the drag on an unanchored 20-net string of gillnets reached 1435 lbs (Salvador and Kenney 2002). These studies suggest that the forces applied during normal fishing operations are considerably lower in most cases for lighter gear sets than the 1700 lb RBS rope that would reduce lethal entanglements. When gear is being towed (similar to the situation of an entangled whale), loads on the ropes become much greater. If RBS ropes were designed to break at the load applied when gear is being towed by a whale, this would allow for normal fishing activity to continue but might provide a better chance for a whale to break free before a severe entanglement occurred.

Rope used for fishing is stronger than needed, because strength gives fishermen a margin of security against the potential weakening effects of weather, repeated hauling stress, abrasion, and rope age. If RBS ropes were to be used, the development of a more abrasion and weather resistant rope might mitigate the chances of higher gear loss due to weaker ropes with unchanged abrasion resistance. While there is likely to be reluctance to using RBS ropes, preliminary trials of RBS ropes of 600 and 1,200lbs by lobstermen in the Gulf of Maine in 2006 and 2007 indicated that the ropes were fishable in some areas, and that fishermen were receptive to the concept (Bycatch Consortium, unpublished data). In addition, RBS ropes may improve safety at sea by preventing dangerous “hangdown” situations that can occur when the bottom gear gets caught on rocks during hauling. It may also reduce the chance that a set of bottom gear could get dragged from where it was set when a vertical line is snagged by an entangled whale or by a passing vessel and thus provide a possibility of grappling for the bottom gear. Accidental towing of gear is considered one of many reasons gear is lost (Prybot 2006). In areas where this recommended breaking strength cannot be used to fish, the development and implementation of other bycatch mitigation techniques such as rope-less fishing techniques should be tested.

This work suggests that the development and implementation of reduced breaking strength ropes could lead to a significant reduction of whale mortality and serious injury from entanglement. Previous management attempts to reduce entanglements of large whales have required weak links between the top of the vertical line and the surface buoy system of pot and gillnet gear and also between gillnet panels. There is no evidence that this has been at all effective (Pace et al 2014). With RBS ropes, the goal would be to make the entire vertical line weaker, rather than only specific points in the gear. This would give an entangled whale a better chance of breaking free wherever it hits the vertical line in the water column.

This conservation approach may be a useful tool for practitioners around the world to integrate into fisheries management regimes for any rope-based resource extractions. Short-term evaluation of its efficacy could be determined by using a unique rope color or gear mark to assess the injury severity and configuration risk for RBS ropes found on whales. Long term efficacy can be determined by monitoring entanglement rates and severity levels in the target population. Considering that entanglement is one of the most urgent conservation issues facing marine mammals today, adopting this relatively simple gear modification represents a badly needed option for reducing the number of unnecessary deaths and suffering by whales around the world.

SUPPORTING INFORMATION

Supporting information on methods of rope analyses and associated data (Appendix S1 and S2), a RW case study example (Appendix S3), and entanglement injury and configuration severity criteria (Appendix S4) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Table 1. Rope polymer type, range of diameter, range of new and estimated breaking strength, and apparent condition

Polymer type Range of diameters in inches Range of new (estimated) breaking strength in lbs	Very Poor	Poor	Fair	Good	Very Good	**Total # of ropes (% of total)**
Polypropylene 0.177-0.933 650-12,000 (180-7,639)	4	6	8	18	18	**54 (41%)**
Polypro/PET 0.312-0.654 1,900-6,800 (700-5,440)	3	6	3	14	8	**34 (26%)**
Polysteel 0.307-0.685 2,500-11,500 (756-8,392)	1	1	5	13	6	**26 (20%)**
Polysteel/PET 0.303-0.417 2,400-4,300 (1,522-2,727)			1	4	2	**7 (5%)**
Polypro/PET/Lead 0.335-0.409 1,700-2,000 (1,700-2,000)					5	**5 (4%)**
Polysteel/Lead 0.339-0.787 2,500-11,500 (1,410-8,776)				1	2	**3 (2%)**
Nylon 0.618-0.638 8,910 (5,346-8,910)			1		1	**2 (2%)**
Polypro/Lead 0.323 1,700 (1,360)				1 (1.0)		**1 (1%)**
	8 (6%)	**13 (10%)**	**18 (14%)**	**51 (39%)**	**42 (31%)**	**132**

Table 2. Summary of diameter and breaking strength ranges of ropes removed from large whales off the eastern US and Canada. Nominal rope diameters are those typically used by their manufacturers and lie within or near the range of measured diameters.

Range of measured rope diameters (inches)	Nominal rope diameter (inches)	Number of ropes (% of total) retrieved from 70 large whales	Tally of strongest rope (% of total) for each case	Range of breaking strengths new (estimated)
0.177 – 0.185	3/16" (0.187)	2 (<2%)	2 (<3%)	650 (180 – 297)
0.252	1/4" (0.25)	1 (<1%)	0 (0%)	1,130 (904)
0.287 – 0.339	5/16" (0.312)	36 (27%)	15 (21%)	1700 – 2600 (340 – 2,759)
0.346 – 0.406	3/8" (0.375)	40 (30%)	22 (31%)	2,000 – 3,400 (486 – 3,075)
0.407 – 0.449	7/16" (0.437)	18 (14%)	7 (10%)	2,000 – 5,000 (700 – 4,335)
0.469 – 0.512	1/2" (0.5)	9 (7%)	5 (7%)	3,780 – 5,550 (900 – 5,640)
0.539 – 0.591	9/16" (0.562)	15 (11%)	10 (14%)	4,590 – 7,000 (1,580 – 7,391)
0.618 – 0.685	5/8" (0.625)	6 (5%)	5 (7%)	6,800 – 9,000 (1,360 – 8,910)
0.748 – 0.787	3/4" (0.75)	4 (3%)	3 (<5%)	7,500 – 11,500 (6,120 – 8,776)
0.933	1" (1.0)	1 (<1%)	1 (<2%)	12,000 (2,400)

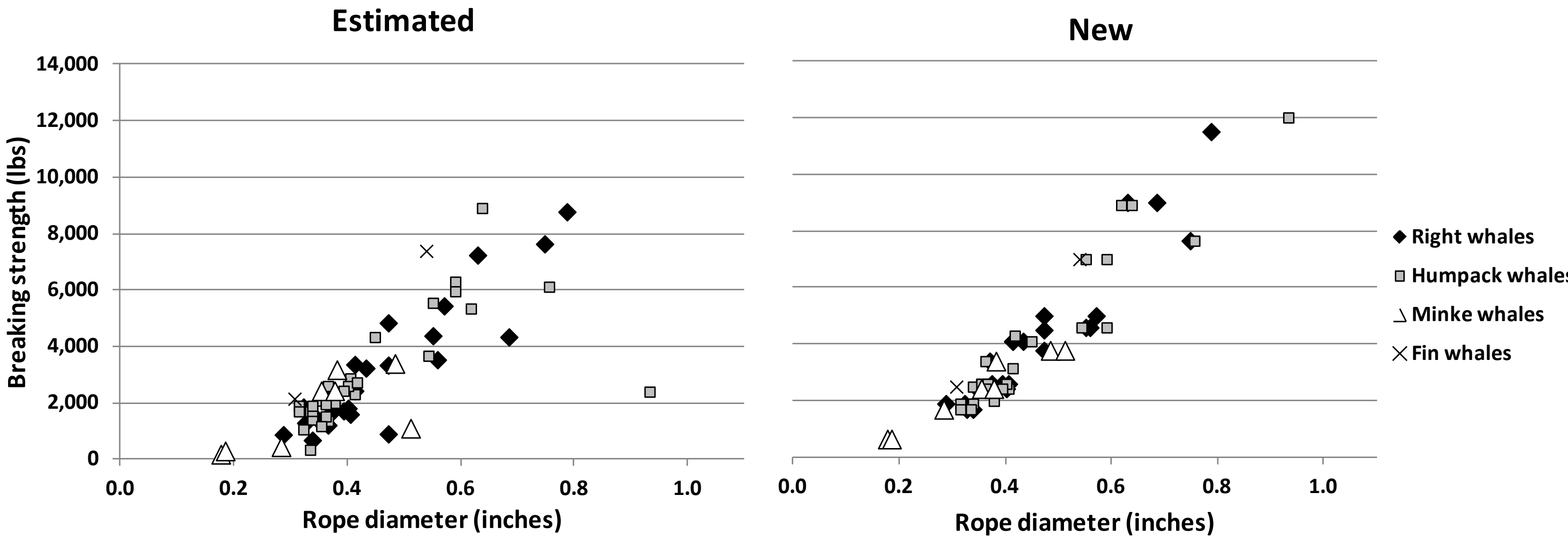
FIGURE CAPTIONS

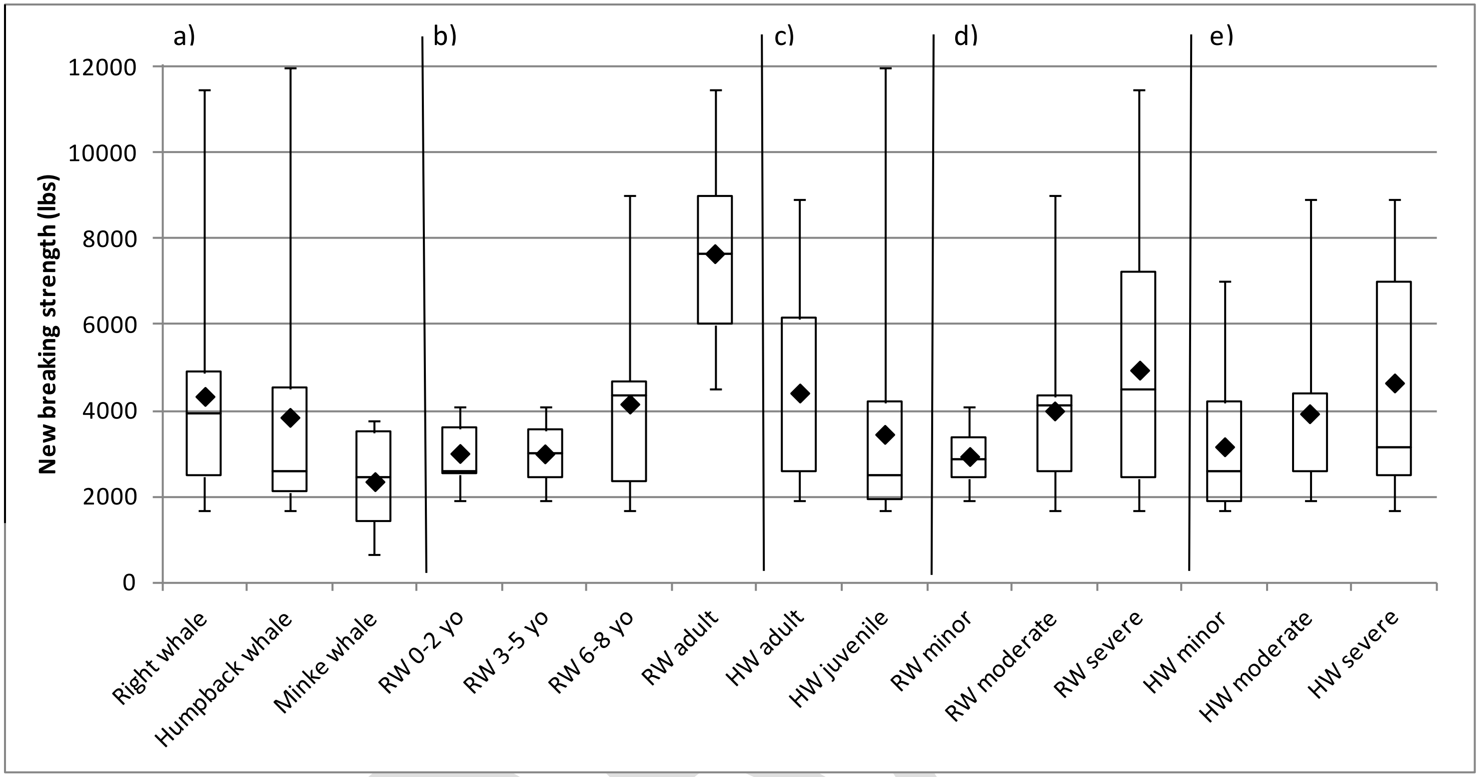
Figure 1. Estimated and new breaking strength and diameter of all ropes removed from right, humpback, minke, and fin whales

Figure 2a-e. Summary statistics by species, age class and injury severity (where available). The box represents the middle 50% of measurements collected in each category, the line through the box is the median, the diamond is the mean and the whiskers represent the minimum and maximum.

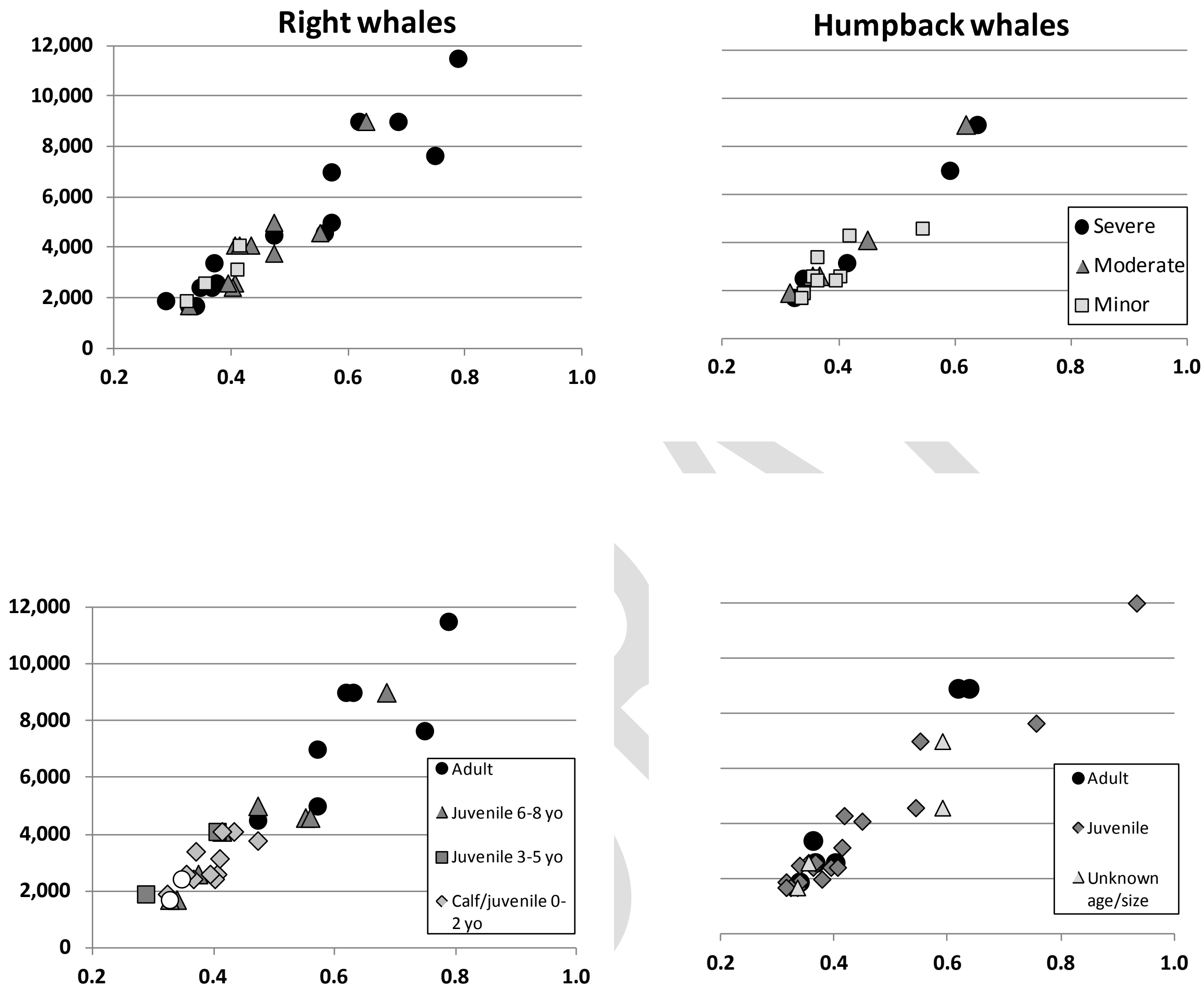
Figure 3. Right and humpback whales compared to rope strength and diameter by injury severity (top) and age (bottom).

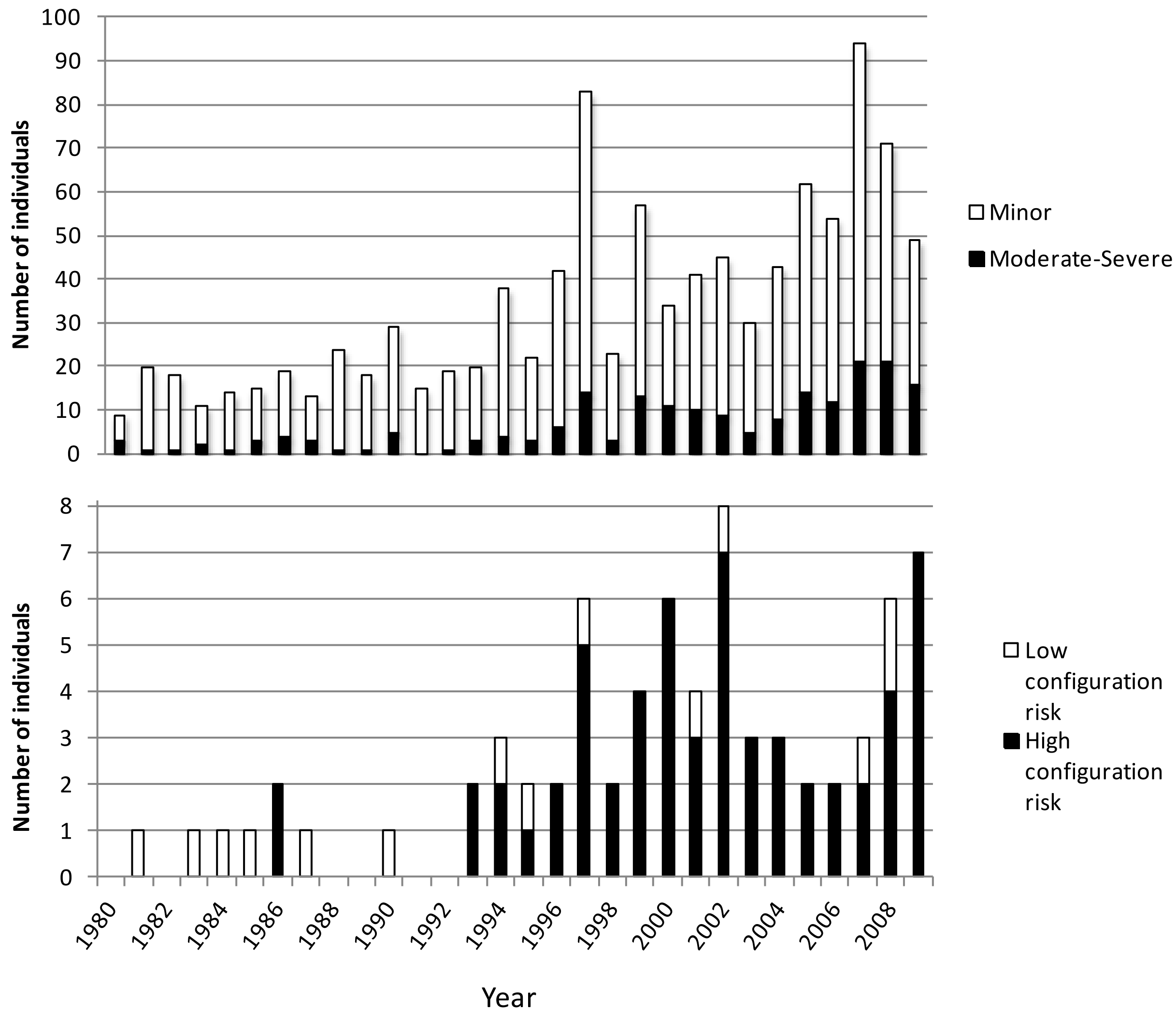
Figure 4. Frequency of right whale entanglements by injury severity and gear configuration risk levels by year.


Estimated
New
Breaking strength (lbs)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0.0
0.2
0.4
0.6
0.8
1.0
Rope diameter (inches)
Right whales
Humpack whales
Minke whales
Fin whales



a)
b)
c)
d)
e)
New breaking strength (lbs)
12000
10000
8000
6000
4000
2000
0
Right whale
Humpback whale
Minke whale
RW 0-2 yo
RW 3-5 yo
RW 6-8 yo
RW adult
HW adult
HW juvenile
RW minor
RW moderate
RW severe
HW minor
HW moderate
HW severe


Right whales
Humpback whales
12,000
10,000
8,000
6,000
4,000
2,000
0
0.2
0.4
0.6
0.8
1.0
Severe
Moderate
Minor
Adult
Juvenile 6-8 yo
Juvenile 3-5 yo
Calf/juvenile 0-2 yo
Adult
Juvenile
Unknown age/size


100
90
80
70
60
50
40
30
20
10
0
Number of individuals
Minor
Moderate-Severe
8
7
6
5
4
3
2
1
0
Number of individuals
Low configuration risk
High configuration risk
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Year