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Assessing changes in numbers and distribution of large whale entanglements in Newfoundland and Labrador, Canada[1]

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ABSTRACT

Entanglements of large whales in commercial fisheries in Newfoundland and Labrador, Canada, have been consistently recorded since 1979, as part of a program aimed at releasing captured animals and reducing costs to fishermen. This data set represented an opportunity to identify fisheries posing particular entanglement risks to local whale populations. Data were assessed over the periods 1979–1992 and 1993–2008, corresponding to distinct phases in fisheries distribution and intensity. Between 1979 and 2008, 1,209 large whale entanglements were recorded in Newfoundland and Labrador. These were mostly humpback whales (*Megaptera novaeangliae*; 80%) and minke whales (*Balaenoptera acutorostrata*; 15%). Dramatic declines in reported inshore whale entanglement rates were observed following the 1992 moratorium on Atlantic cod (*Gadus morhua*) fisheries. Recently, more entanglements have been reported further offshore, largely due to expansion of fisheries targeting snow crab (*Chionoecetes opilio*). For all whale species, entanglement

[1]This article is dedicated to Dr. Jon Lien (1939–2010), who was instrumental in setting up the Large Whale Entrapment Program through Memorial University's Whale Research Group, and who for more than 30 yr worked tirelessly on behalf of both whales and fishermen in Newfoundland and Labrador. A large proportion of the data described here was gathered by Jon and his associates, and his role in resolving whale entanglements in Newfoundland fisheries cannot be overstated. He will be sorely missed.

rates and associated mortality rates varied considerably in different fishing gear. Fractions of humpback and minke whales found dead in different fishing gear differed substantially, with minke whales far more likely to be found dead than humpback whales.

Key words: Newfoundland, Canada, northwest Atlantic, humpback whale, minke whale, entanglement, bycatch, fisheries, snow crab, Atlantic cod.

Impacts of Whale Entanglements in Fishing Gear

Large numbers of marine megafauna, including marine mammals, sharks, seabirds, and marine turtles, are unintentionally captured annually in commercial, artisanal, and recreational fisheries worldwide (Perrin *et al.* 1994, Tasker *et al.* 2000, Baum *et al.* 2003, Ferraroli *et al.* 2004, Read *et al.* 2006). This may have significant conservation implications for such species through reduced adult survival, leading to population crashes, and reduced scope for subsequent recovery (Musick 1999). Entanglement of whales in fishing gear, as defined by the International Whaling Commission (IWC 2010), involves the presence of line, netting, or other materials wrapped around body areas of a whale and may include cases in which animals are towing gear or anchored by gear. This constitutes a major threat to large whales worldwide, often resulting in injury and mortality (*e.g.*, Perrin *et al.* 1994, Knowlton and Kraus 2001, Robbins and Mattila 2004, Johnson *et al.* 2005). Although global estimates are lacking, such entanglements are likely widespread amongst many of the world's baleen whale populations (Read *et al.* 2006). Reports of entangled large whales typically involve stationary fishing gear, for example, gill nets, pots, seines, and traps, as well as lines attached to moorings and buoys (Johnson *et al.* 2005). Such entanglements may occur when whales collide with such fishing gear and fail to extricate themselves when nets, lines, *etc.* are snagged around various parts of their bodies, such as the jaw, flippers, dorsal fin, tailstock, and flukes (Knowlton and Kraus 2001, Robbins and Mattila 2004, Johnson *et al.* 2005); whales may become further entangled while attempting to escape (Weinrich 1999). Entanglements may lead to whales dying through drowning or asphyxiation when caught at depth. If a whale is still able to reach the surface and breathe, it may remain anchored; alternatively, it may swim away, towing fishing gear with it. Animals released from extended entanglements may experience considerable difficulties in swimming normally even following removal of gear (Knowlton and Kraus 2001). As gear is dragged, the force it exerts on adjacent tissues may lead to injury or even death through tissue damage, increased infection risk, and septicemia (Moore *et al.* 2004). In addition, towing gear may negatively impact whales' swimming and foraging capabilities, increasing risk of starvation, ship collision, or predation (Kot *et al.* 2009). In areas where the problem has been studied, considerable numbers of whales have been recorded entangled in fishing gear or showing evidence of previous entanglement through scarring and other injuries, including humpback whales (*Megaptera novaeangliae*), North Atlantic right whales (*Eubalaena glacialis*), gray whales (*Eschrichtius robustus*), and minke whales (*Balaenoptera acutorostrata*; Robbins and Mattila 2004, Bradford *et al.* 2009, Neilson *et al.* 2009, Song *et al.* 2010). Entanglement in fishing gear thus represents a significant source of anthropogenic injury and mortality for large whales (Glass *et al.* 2010). There is an urgent need for accurate, long-term information on entanglement frequencies and mortality rates in different fisheries, taking into account changes to the fisheries involved.

Fisheries in Newfoundland and Labrador, Canada

Fishing has been the mainstay of the Newfoundland economy from initial European colonization in the 17th century until recently, with Atlantic cod (*Gadus morhua*) by far the most important target species, targeted using handlines, gill nets, and cod traps (a large, box-like type of fish trap; Hutchings and Myers 1995, Templeman 1966, Lear 1998, He and Inoue 2010). In 1992, following severe declines of stocks throughout Atlantic Canada, the Canadian government announced a moratorium on fisheries for Atlantic cod (DFO 1992, Hutchings and Myers 1994, Sinclair and Murawski 1997); to date, there are no indications of any significant recovery (Anonymous 2005, Brattey *et al*. 2009). Other fisheries, including the pelagic gill net fishery for Atlantic salmon (*Salmo salar*), were also closed during this period for similar reasons (O'Connell *et al*. 2005). This encouraged the development of fisheries targeting other species (Schrank 2005), with the pot fishery for snow crab (*Chionoecetes opilio*) assuming particular significance. This fishery is now widely practiced in deep waters in inshore and offshore areas around Newfoundland and Labrador (Taylor *et al*. 2008).

Following these significant changes to the Newfoundland and Labrador fishing industry, there is a widespread perception that total amounts of fishing gear (particularly gill nets and fish traps) have declined significantly since the early 1990s as a result of management measures aimed at conserving fish stocks (including quota limitations, gear restrictions, licensing conditions, area closures, and shorter fishing seasons; Tasker *et al*. 2000). This is certainly true for fish traps (especially cod traps), although part of the gill net effort that historically targeted Atlantic cod may have been redirected toward other species; however, no detailed information is available. Concurrently, pot gear fisheries (particularly snow crab, but also lobster [*Homarus americanus*], toad crab [*Hyas* sp.], and whelks [*Buccinum undatum*]) have expanded widely since the 1992 cod moratorium (Schrank 2005).

Whale Release and Strandings Program

The Whale Release and Strandings Program in Newfoundland responds to calls from fishermen and others[2] concerning accidental entanglements in fishing gear of large marine animals such as whales, leatherback sea turtles (*Dermochelys coriaca*), and basking sharks (*Cetorhinus maximus*). The program has been run by Memorial University of Newfoundland's Whale Research Group (1979–1998), Canadian Coast Guard (1999–2000), and the independent Whale Release and Strandings Group (2001–present). Original data of reported entanglements from 1979 to 2008 have been summarized by Lien (1994) and in numerous subsequent Release Program research reports (available at http://www.newfoundlandwhales.net). Although there are no formal protocols in place to train fishermen in reporting, it is in their financial interest to do so. The factual occurrence of all entanglement reports that could be verified has been confirmed by the Release Program or other independent observers.

The goal of the present study was to assess whether changes to Newfoundland and Labrador fisheries since 1992, as outlined above, had led to changes in entanglement and mortality rates of large whales, using the Release Program's data set over the period 1979–2008. Specifically, the data set was analyzed to determine whether any changes had occurred in terms of whale species caught, fishing gear involved,

[2]The vast majority of reports originate from commercial fishermen, though some were provided by Fisheries Observers, tour boat operators, DFO surveillance flight crews, and Canadian Coast Guard staff.

outcomes of release attempts, and spatial distribution (inshore *vs.* offshore waters), comparing data from 1979 to 1992 (prior to the Atlantic cod moratorium) with data from 1993 to 2008 (after the moratorium had come into effect).

Methods

Entanglement Data

Entanglement data were collected through the normal operations of the Release Program by staff and volunteers. For each reported entanglement, Release Program staff recorded data on the date, location (latitude/longitude), species, number of animals, type of fishing gear involved, and outcome of any release attempt. It is important to note that the vast majority of reported entanglements involved whales anchored in stationary gear, rather than swimming while dragging gear behind them, a circumstance that greatly facilitated release attempts. Location of entanglements was often recorded based on the nearest adjacent community, but in recent events, locations were recorded through Global Positioning System (GPS) technology on board attending vessels. The outcome of the release attempt could be one of the following:

(1) The whale was successfully released (either by the Release Program's Entanglement Team or the gear's owner), though sometimes still towing gear.
(2) The whale was confirmed dead, entangled in fishing gear.
(3) The whale freed itself, sometimes still towing parts of gear, after having been reported as entangled but before anyone could attend to the animal.
(4) The outcome was unknown because a whale was spotted towing gear but the Entanglement Team could not locate the animal.

In a few cases, whales washed ashore dead without gear attached but with marks indicating recent entanglement. These records have been retained in the data set but not used for more in-depth analyses.

Data Aggregation

Entanglement data were aggregated temporally into two periods, each corresponding to a distinct phase in distribution and intensity of different fisheries:

1979–1992: An intensive fishery for Atlantic cod, undertaken in both inshore and offshore waters. Toward the end of this period, large amounts of fishing gear were used in inshore waters in an attempt to maintain cod catch levels. A moratorium on Atlantic cod was enacted during the 1992 fishing season.

1993–2008: Following the 1992 cod moratorium, several fisheries expanded (lumpfish [*Cyclopterus lumpus*] and snow crab) or were newly developed (monkfish [*Lophius americanus*]), while others (salmon) were closed. Subsequently, fisheries for snow crab, northern shrimp (*Pandalus* sp.), and Greenland halibut (*Hippoglossoides hippoglossoides*) have become dominant offshore. Fisheries for Atlantic cod remain closed or are limited to small areas under severely reduced quota.

Data were also aggregated spatially on the basis of large-scale areas, broadly corresponding to inshore and offshore components of Northwest Atlantic Fisheries Organization (NAFO) Management Units, as determined by the boundaries of relevant NAFO Subzones immediately adjacent to land (see also Fig. 1):

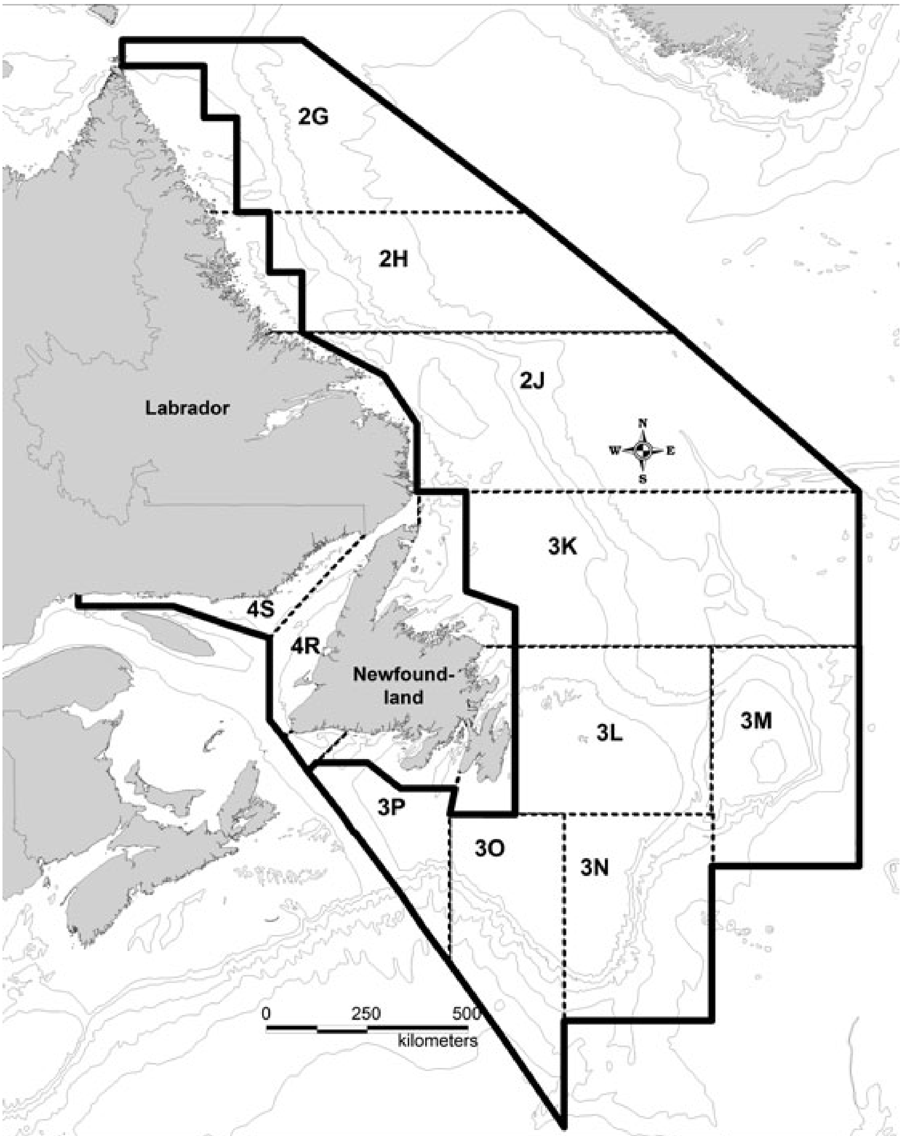

Figure 1. Spatial division of Newfoundland and Labrador waters used in this study, based on NAFO Management Unit boundaries (dashed lines; 3M and 3N truncated for the present study). Inshore portions of NAFO Management Units are combined as "inshore" waters, with the remainder considered "offshore." Quebec North Shore (4S) is included here as two entanglements were reported near the Labrador border, but otherwise falls outside the jurisdiction of the Release Program.

(1) Inshore waters off Labrador and Newfoundland (including NAFO Subzones 2Ga, 2Gc, 2Ge, 2Ha, 2Hd, 2Ja, 2Jd, and 2Jm; 3Ka, 3Kd, 3Kh, 3Ki, 3La, 3Lb, 3Lf, and 3Lj; 3Pn, 3Psa, 3Psb, 3Psc, and 3Lq; 4Ra–d and 4S).
(2) Offshore waters across the Labrador and Newfoundland Shelf, including the Grand Banks and Flemish Cap (covered by NAFO management units 2G, 2H, 2J, 3K, 3L, 3M, 3N, 3O, and 3Ps, except for those inshore areas identified above).

Finally, entanglement data were aggregated according to the fishing gear involved:[3]

(1) Gill nets, including bottom-set nets targeting a diverse range of demersal fish species including Atlantic cod, lumpfish, Greenland halibut, white hake (*Urophycis tenuis*), monkfish, skates (Rajidae), redfish (*Sebastes* sp.), and winter flounder (*Pseudopleuronectes americanus*), and pelagic gill nets, targeting Atlantic herring (*Clupea harengus*) and Atlantic salmon;
(2) pots targeting snow crab, toad crab, American lobster, and whelks;
(3) fish traps targeting Atlantic cod, capelin (*Mallotus villosus*), mackerel (*Scomber scombrus*) and squid (*Gonatus* sp.);
(4) rope (any kind of rope or mooring, without fishing gear attached), and
(5) other identified fishing gear (*e.g.*, discarded trawl gear).

In some cases, only the generic gear type was identified (*e.g.*, "Gill nets" without target species), in which case the gear type was recorded as "Unknown" (*e.g.*, "Gill nets—unknown").

Impact Analysis of Changes to Fisheries

Linear regression was used to model the relationship between changes to fisheries following the 1992 cod moratorium and reported whale entanglements, for the time period 1979–2008, using the software package R (R Development Core Team 2009). Linear time series models were generated using time (t, in years) and dummy variables representing the two time periods before and after the 1992 cod moratorium. Reparameterization of the time difference was used to produce model coefficients that led to easy interpretation. Changes in overall fit of the model using the reparameterized predictors were tested using analysis of deviance. These results were nonsignificant suggesting that the reparameterization had no effect on the outcome of the model and therefore these parameters were retained. The goodness of fit of each model was assessed using Akaike's Information Criterion (AIC; Akaike 1973). The Durbin–Watson test was applied to investigate the presence of autocorrelation in the final model (Durbin and Watson 1971). These tests were undertaken for all entanglements combined as well as for individual species.

[3]It is worth emphasizing that gears lumped together under these broad categories (*e.g.*, gill nets), but used to target different fish species, are often quite different in terms of mesh size, soak time, number of nets per set, deployment depth, *etc*. As such, the entanglement risk they pose to large whales will vary significantly.

Mortality Rates for Humpback and Minke Whales

For each year t within a given time period T, the relative risk of a particular gear type Y to entangled whale species X was described in terms of the fraction of animals reported dead (%Mort), defined as:

$$\%\text{Mort}(\text{whale species } X, \text{ year } t) = \frac{\#\text{ of whales of species } X \text{ reported dead in fishing gear } Y}{\text{Total }\#\text{ of whales of species } X \text{ reported in fishing gear } Y}.$$

Subsequently, an Average %Mort ($\%\text{Mort}_{\text{Avg}}$) value, covering the total number of entanglements in gear Y within all the years t contained within period T, was defined as:

$$\%\text{Mort}_{\text{Avg}}(\text{species } X,\ \text{gear } Y, \text{ Period } T) = \frac{\%\text{Mort}(\text{whale species } X, \text{ gear } Y, \text{ year } t)}{T}.$$

$\%\text{Mort}_{\text{Avg}}$ values of humpback and minke whales (all regions combined) were compared within and across both time periods. Coefficients of variation (CV) were calculated for each $\%\text{Mort}_{\text{Avg}}$ value, as follows:

$$\text{CV} = \frac{s\,(\%\text{Mort}(\text{whale species } X, \text{ gear } Y, \text{ period } T))}{|\%\text{Mort}_{\text{Avg}}(\text{whale species } X, \text{ gear } Y, \text{ period } T)|}.$$

This allowed investigation of the extent to which $\%\text{Mort}_{\text{Avg}}$ values might have changed following the 1992 cod moratorium.

Results

Regional Overview of Entanglements

A total of 1,209 large whale entanglement events were recorded between 1979 and 2008, from all areas around Newfoundland and Labrador. Of these, 1,183 (almost 98%) were reported in inshore waters (see Table 1). Two records were not included in

Table 1. Summary of reported large whale entanglements from 1979–2008 (all regions), by species.

Area	Bowhead whale	Fin whale	Humpback whale	Minke whale	North Atlantic right whale	Orca	Unknown	Grand total
Inshore	1	11	945	182	1	1	42	1,183
Offshore	0	0	20	1	0	0	3	24
Grand total	1	11	965	183	1	1	45	1,207
Fraction of grand total	<0.01	0.01	0.8	0.15	<0.01	<0.01	0.04	

subsequent analyses as they occurred beyond the jurisdiction of the Release Program, leaving 1,207 records.

Humpback whales were the most commonly reported species with 965 entanglements (approximately 80% of the total). Minke whales were the second most commonly reported species, involved in 183 reported entanglements (approximately 15% of the total). Other species were reported very rarely, including fin whale (*Balaenoptera physalus*; 11 events), North Atlantic right whale, bowhead whale (*Balaena mysticetus*), and killer whale (*Orcinus orca*; one event each). In 45 cases (4%), whales could not be identified to species, often because they were reported as towing gear but could not be relocated. Nearly all entanglements involved single animals. In two cases, two animals (both humpback whales) were reported entangled together in the same gear. There are four records of one member of a mother–calf pair becoming entangled, with the other member standing by (two with the calf entangled and two with the mother entangled). Other species were only recorded as single individuals. In this study, an "entanglement" involves only one individual unless noted otherwise.

Nearly 75% of all recorded entanglements (900 cases) occurred during 1979–1992. This equates to an average annual entanglement rate of 64.3 whales/yr (all species combined) during this period. However, there was strong interannual variability in entanglement rates within these periods; a particularly high number (142) of entanglements was recorded in 1991, immediately prior to the 1992 cod moratorium. Following the moratorium, this rate declined dramatically to 19.2 whales/yr during 1993–2008.

During 1979–1992, the vast majority of entanglements (>99%) were reported from inshore waters. However, following the cod moratorium, the number of entanglements reported from offshore waters rose, up to approximately 8% of total reported cases during 1993–2008. Most reported offshore entanglements involved humpback whales.

Modeling Results

Linear regression was used to model the relationship between changes to fisheries following the 1992 cod moratorium and reported whale entanglements, for the time period 1979–2008. Models were created for all entanglements combined, as well as for humpback whales separately. No modeling was attempted for minke whales or any of the other, rarely encountered species, due to low counts and the absence of data (*i.e.*, no reported entanglements) in some years.

For all entanglements combined, the final model, selected based on AIC was:

$$\hat{y} = 19.5 + 78.96x_1 + 4.46x_2.$$

When looking solely at humpback whale entanglements, the final model, selected based on AIC, was:

$$\hat{y} = 13.88 + 73.80x_1 + 4.61x_2.$$

For both models, $\hat{y}$ is the predicted number of whales entangled, x_1 is a dummy variable distinguishing entanglements during the period up to and including 1992 (premoratorium, or 0) from those in the period after 1992 (postmoratorium, or 1), and dummy variable x_2 represents the model estimate of the slope of the annual entanglement trend between 1979 and 1992, before the 1992 cod moratorium.

A third dummy variable, x_3, representing the model estimate of the slope of the annual entanglement trend between 1993 and 2008 following the moratorium, was found to be not significant prior to final model selection. No autocorrelation was present in these final models.

The above models indicated that, for all whale entanglements combined, there was a significant decrease in entanglements between the two periods ($P < 0.001$). Because the year 1991 potentially represented anomalously high levels of entanglement (142 reports), the model was also run without this year; these results were also significant ($P < 0.001$). Using Type III ANOVA, both variables x_1 and x_2 were shown to explain a significant proportion of the overall variation ($P < 0.001$ in both cases), indicating that entanglement rates had declined significantly following the 1992 cod moratorium, and that there had been a generally upward trend in entanglements in the years from 1979 to 1992 (in contrast to entanglement rates in the years following the moratorium). The greatest change was caused by a reduction in entanglements of humpback whales, particularly in cod traps, which were largely phased out following the cod moratorium.

Overview of Fishing Gear Involved in Entanglements

Of 1,207 entanglements reported within the Newfoundland and Labrador area between 1979 and 2008, 1,123 (approximately 93%) could be assigned to at least one of the five generic gear type categories defined above (Gill nets, Pots, Traps, Rope, and Other Gear). The remainder involved entanglements where gear could not be identified. Humpback whales represented 50%–95% of all entanglements between 1979 and 2008. Before 1992, most entanglements of both humpback and minke whales occurred in Traps and Gill nets, but entanglements involving Pots became more common following the moratorium (see Fig. 2). Humpback whale entanglements declined considerably following the 1992 cod moratorium, but for minke whales, a comparable trend was less obvious. Although there was some indication that minke whale entanglements declined immediately following the moratorium, regrettably there were insufficient data for in-depth linear regression analysis to assess the significance of such a decline (see Fig. 2). Other species were entangled too infrequently for any interannual trends to be assessed. All 11 fin whale entanglements involved Gill nets, while the single North Atlantic right whale entanglement occurred in a Trap. The single killer whale entanglements involved Rope without gear attached, while the single bowhead whale entanglement involved an anchored boat mooring in a harbor. Unidentified whales were reported in all gear categories apart from Other Gear.

Importance of Specific Fishing Gear

Within the broad gear categories described above, there were clear differences in entanglement frequencies for particular gear types (see Table 2, Table S1). Among all entanglements (*i.e.*, all species, for all years) involving gill nets, most entanglements (approximately 69%) occurred in benthic gill nets targeting Atlantic cod and other groundfish. Entanglements in pelagic gill nets or drift nets accounted for a further 18% of all cases, with most of these caused by the salmon fishery. Specific gear type was not recorded in 13% of gill net entanglements. Cod traps were the most common fish trap type involved in entanglements, causing approximately 92% of all such events. Approximately 60% of all pot entanglements involved pots fishing

Table 2. An assessment of $\%Mort_{Avg}$ values of humpback and minke whales in different fishing gear per year within the 1979–1992 and 1993–2008 periods (all areas combined). Total sample size (n_{total}), $\%Mort_{Avg}$ values, and coefficients of variation (CV) are provided in brackets for each case. N/A indicates that no entanglements were recorded or, in the case of CVs, that no CV could be calculated as only a single animal was reported during the time period in question. $\%Mort_{Avg}$ values equal to or exceeding 0.10, where $n \geq 10$ entanglements during the period under study, are indicated in bold to denote the most important fisheries.

		Humpback whale				Minke whale			
		1979–1992		1993–2008		1979–1992		1993–2008	
Fishing gear		n_{total}	$\%Mort_{Avg}$ (CV)	n_{total}	$\%Mort_{Avg}$ (CV)	n_{total}	$\%Mort_{Avg}$ (CV)	n_{total}	$\%Mort_{Avg}$ (CV)
All gear combined (gill nets, traps, pots)		684	**0.17 (0.53)**	150	**0.19 (0.99)**	114	**0.65 (0.32)**	48	**0.60 (0.53)**
Gill nets	Cod	210	**0.11 (0.84)**	30	0.04 (3.00)	27	**0.47 (0.86)**	13	**0.42 (1.01)**
	Herring	3	0.00 (N/A)	8	0.17 (2.45)	1	0.00 (N/A)	0	N/A
	Salmon	64	0.09 (1.84)	0	N/A	15	**0.48 (1.05)**	1	0.00 (N/A)
	Lumpfish	8	0.00 (N/A)	10	**0.32 (1.47)**	2	0.00 (N/A)	8	0.30 (1.49)
	Monkfish/skate	0	N/A	3	0.33 (1.73)	0	N/A	0	N/A
	Winter flounder	8	0.00 (N/A)	16	**0.25 (2.00)**	3	1.00 (N/A)	8	0.58 (0.84)
	Unidentified	29	0.05 (1.85)	11	**0.10 (2.45)**	5	1.00 (0.00)	2	0.50 (1.41)
Pots	Snow crab	1	1.00 (N/A)	25	**0.23 (1.62)**	**0**	N/A	1	1.00 (N/A)
	Toad crab	0	N/A	0	N/A	0	N/A	1	1.00 (N/A)
	Whelk	4	0.00 (N/A)	**6**	0.00 (N/A)	0	N/A	3	1.00 (N/A)
	Lobster	0	N/A	2	0.00 (N/A)	0	N/A	3	0.00 (N/A)
	Unidentified	0	N/A	1	0.00 (N/A)	0	N/A	0	N/A
Traps	Capelin	4	0.00 (N/A)	16	**0.14 (2.65)**	0	N/A	2	1.00 (N/A)
	Mackerel	5	0.17 (1.73)	2	0.00 (N/A)	0	N/A	6	0.25 (2.00)
	Cod	347	**0.23 (0.41)**	18	**0.48 (0.87)**	60	**0.79 (0.32)**	0	N/A
	Squid	1	0.00 (N/A)	2	0.00 (N/A)	1	1.00 (N/A)	0	N/A

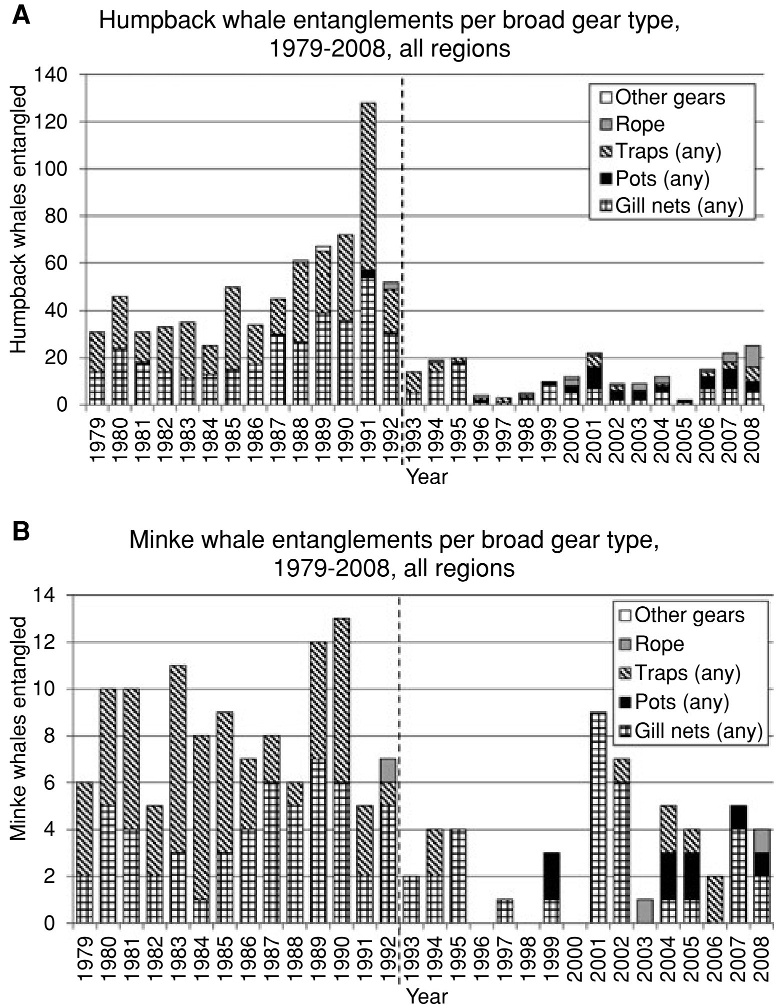

Figure 2. Interannual variability in entanglements of (A) humpback and (B) minke whales (per broad fishing gear category, all regions combined) from 1979 through to 2008. For humpbacks, there is a distinct peak of entanglements involving mainly (cod) traps just prior to the 1992 cod moratorium (indicated in this and subsequent figures by a dotted line). This peak is far less prominent for minke whales (but note smaller sample size). Note that although the reduction in entanglements since the imposition of the cod moratorium is significant, entanglements of both species have continued.

for snow crab, with whelk pots accounting for an additional 24%. Target species was not specified in 5% of entanglements involving pot gear.

In 41 cases, whales were reported entangled in rope without fishing gear attached (but including floats, marker buoys, and anchors), often sighted at sea towing gear. Five entanglements (all involving humpback whales) were caused by other fishing gear, including a capelin seine, a discarded shrimp trawl, an otter trawl, and hook and line gear (two cases). Apart from the shrimp trawl, it is unknown whether this gear had been discarded or lost prior to the entanglement. A further 81 entanglements were reported without any information of fishing gear involved. Finally, seven whales were found dead without fishing gear attached but with net marks indicating recent entanglement.

Resolution of Entanglements

Of 1,209 reported entanglements, most (1,091) whales were reported in the initial stages of entanglement, while still anchored in place by the gear, and their immediate fate following an entanglement was recorded (as Live Release, Dead, or Self-Release; see also Table S1 for details on humpback and minke whales). The remaining 116 whales were not seen again following initial reporting and their fate could not be confirmed. Overall, 600 of these entanglements resulted in a Live Release, where the Entanglement Team, a fisher or another party (*e.g.*, Canadian Coast Guard personnel) successfully released the whale from an entanglement situation (approximately 55% of cases). Regrettably, the result of release attempts undertaken by different actors was not consistently recorded. In 267 cases (24%), whales were found dead in fishing gear, while in 224 cases, whales were considered to have released themselves from entanglements without human intervention (Self-Release; approximately 21%). Assuming optimistically that no live-released or self-released whales died as a result of injuries sustained during the entanglement, this still implies that, at minimum, almost a quarter of all reported entanglements during 1979–2008 led to the death of a whale.

For 242 fatal entanglements, the fishing gear involved could be identified, with various types of fish traps most commonly reported (135 cases, or 56%) for both humpback and minke whales (60% and 45% of all fatal entanglements per species, respectively).

Variability in Entanglements Between Different Gear types

There were distinct differences in the numbers of large whales reported entangled in different gear. Prior to the 1992 cod moratorium, humpback whales, and to a lesser extent minke whales, were most frequently entangled in traps, particularly cod traps, and gill nets, particularly those targeting cod and salmon (Lien 1994, Volgenau *et al*. 1995), with 91% and 89% of entanglements (for humpback and minke whales, respectively) occurring in these three types of fishing gear during this period. Following the 1992 cod moratorium, absolute numbers of entanglements have declined, but the diversity of gear involved in entanglements has increased (see Fig. 3–5). Cod traps and salmon gill nets all but disappeared as a source of entanglements following the 1992 moratorium due to quota restrictions and fisheries closures. However, gill nets (targeting cod and other species such as lumpfish) have remained an important source of entanglement of large whales up to the present day. Fisheries using pots, particularly snow crab and whelk fisheries, have also become more widespread in inshore as well as offshore waters since 1992, and the number of entanglements involving pots has increased accordingly, mostly involving humpback whales (Taylor *et al*. 2008; see also Fig. 3–5).

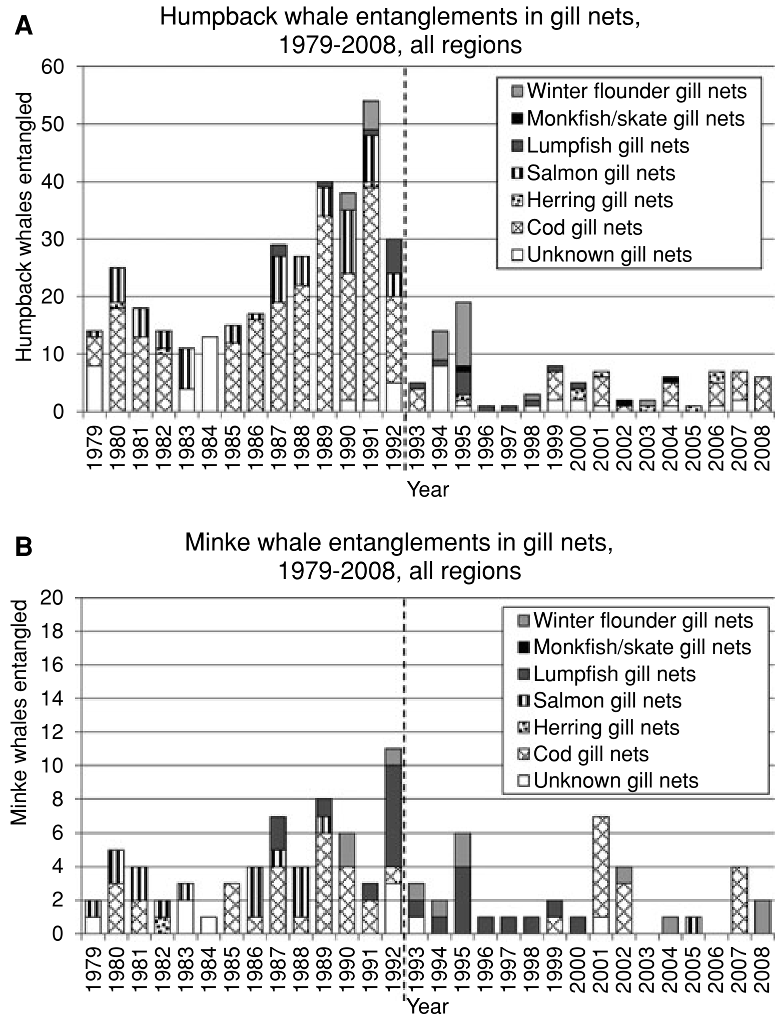

Figure 3. Entanglements of (A) humpback and (B) minke whales in different gill net types, 1979–2008 (all regions combined). The increased number of entanglements in groundfish (mainly cod) gill nets immediately prior to the 1992 Atlantic cod moratorium is particularly evident for humpback whales.

Mortality Rates for Humpback and Minke Whales

$\%\text{Mort}_{\text{Avg}}$ values of humpback and minke whales (all regions combined) were compared within and across both time periods. There was a distinct difference in likelihood of mortality between humpback and minke whales. Overall, humpback whales were often released alive (59%) or succeeded in releasing themselves (25%); they were only found entangled dead in 16% of all cases. In contrast, 34% of minke whales were released alive, and only 6% freed themselves; minke whales

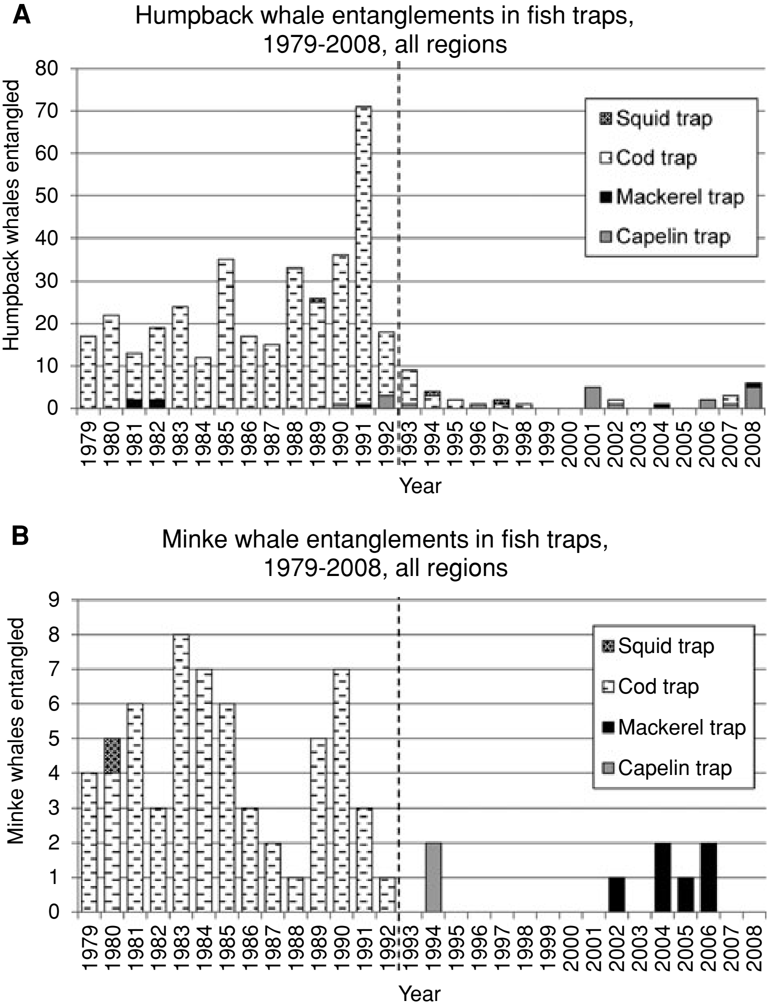

Figure 4. Entanglements of (A) humpback and (B) minke whales in different kinds of fish traps, 1979–2008 (all regions combined). The impact of cod traps during the years prior to the cod moratorium is apparent, particularly for humpback whales.

were found dead in the remaining 60% of entanglements. For all gear combined, $\%\text{Mort}_{\text{Avg}}$(humpback) did not change substantially following the 1992 cod moratorium (from 0.17 [CV: 0.49]) during 1979–1992 to 0.19 [CV: 0.99] during 1993–2008), whereas $\%\text{Mort}_{\text{Avg}}$(minke) declined (from 0.68 [CV: 0.29] during 1979–1992 to 0.51 [CV: 0.70] during 1993–2008; see Table 2). CVs increased as a result of smaller sample sizes in the 1993–2008 period.

Taking into account sample sizes, the highest $\%\text{Mort}_{\text{Avg}}$ values overall for both humpback and minke whales in 1979–1992 were observed in traps (especially cod

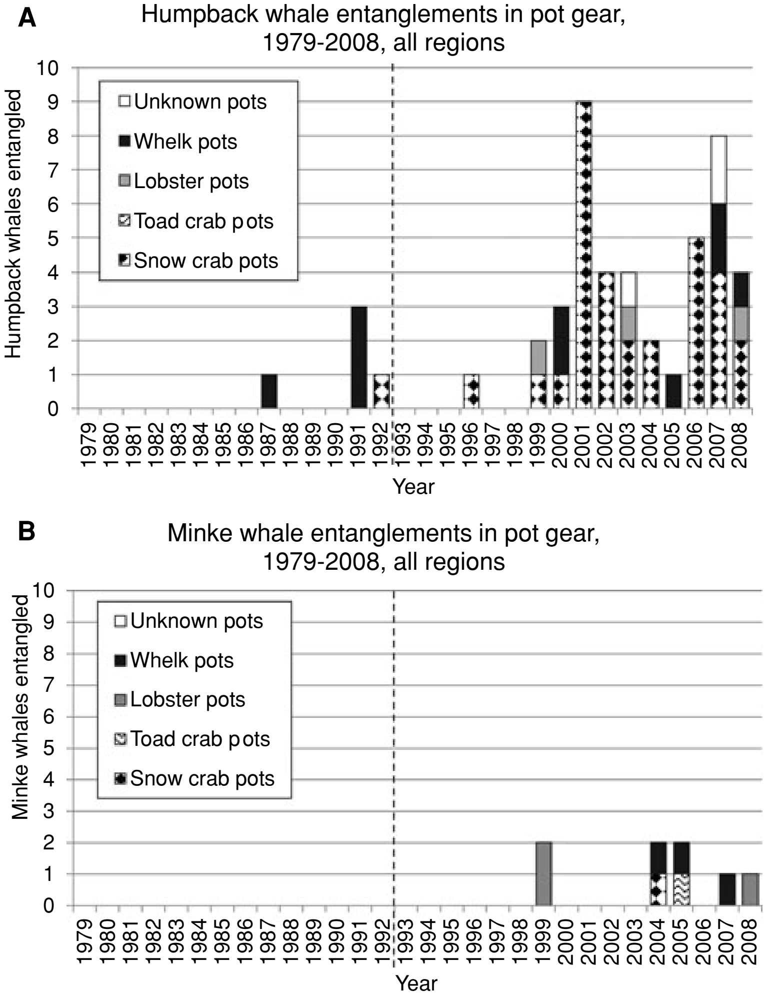

Figure 5. Entanglements of (A) humpback and (B) minke whales in different pot gear, 1979–2008 (all regions combined). Humpbacks appeared more likely than minke whales to be reported entangled in pot gear, and most entanglements of humpback whales occurred in pots targeting snow crab.

traps) and gill nets (especially those targeting cod and salmon). In contrast, in 1993–2008, high $\%\text{Mort}_{\text{Avg}}$(humpback) values were observed in other gear, especially snow crab pots and gill nets targeting lumpfish and winter flounder. For minke whales, $\%\text{Mort}_{\text{Avg}}$ values during 1993–2008 remained high for cod gill nets. This coincided with an apparent increase in $\%\text{Mort}_{\text{Avg}}$(minke) values in several other types of gill nets, fish traps, and pot gear (see Table 2).

When comparing $\%\text{Mort}_{\text{Avg}}$(humpback) and $\%\text{Mort}_{\text{Avg}}$(minke) values for specific gear types during the premoratorium period, $\%\text{Mort}_{\text{Avg}}$(minke) exceeded $\%\text{Mort}_{\text{Avg}}$(humpback) in all fishing gear for which $n \geq 10$ entanglements, including cod gill nets, salmon gill nets, and cod traps. During 1993–2008, $\%Mort_{Avg}$(minke) also exceeded $\%Mort_{Avg}$(humpback) for cod gill nets and most other gill net, fish trap, and pot fisheries, but not for cod traps and salmon gill nets (see Table 2).

Based on these data, a mean of 9.4 humpbacks (CV: 0.64) and 3.0 minke whales (CV: 0.87) were reported entangled each year during 1993–2008, despite large reductions in fishing effort in inshore waters. Using the $\%Mort_{Avg}$ values calculated earlier for all gill nets, pots, and traps combined (see Table 2), this corresponds to a mean of 1.8 humpbacks and 1.4 minke whales reported dead each year in this gear.

Discussion

Changes in Entanglement Rates

The reported prevalence of large whale entanglements in inshore Newfoundland and Labrador waters during the heights of the Atlantic cod fishery has been described previously (*e.g.*, Lien 1994, Volgenau *et al*. 1995), but more recent information has been unavailable. The present results provide, for the first time, an overview of changes to large whale entanglement rates following the drastic changes in the fishing industry precipitated by the collapse of Atlantic cod stocks in the early 1990s. Reports of large whale entanglements in inshore Newfoundland and Labrador waters have clearly declined significantly following the 1992 Atlantic cod moratorium, with total reported entanglement rates down by approximately 65% from 1979–1992 to 1993–2008. This has probably been driven by significant changes in the fishing industry since the early 1990s, including (1) a reduction in overall fishing effort, particularly in inshore waters, accompanied by a concurrent shift of effort into offshore areas; (2) the disappearance of formerly widespread fishing gear implicated in many entanglements, including cod traps and salmon gill nets; and (3) a reduction of the total amount of fishing gear in the water per license, through area closures, license restrictions and shorter fishing seasons.

However, the spatial distribution of entanglements also appears to have changed, with more entanglements now being reported from offshore waters. Pots, especially those used to target snow crab, have emerged as a new and potentially significant source of large whale entanglements. Because the snow crab fishery is prosecuted over such a large area, and monitoring effort is limited, the number of entanglements involving snow crab pots reported here is likely negatively biased. However, offshore reporting coverage is presently insufficient to confirm a genuine offshore shift in entanglement risk.

Whale Distribution and Abundance

Apart from changes in fisheries, several additional factors may have influenced reported changes in entanglement rates. The spatial distribution of whales (especially humpback whales) in Newfoundland waters during the summer period is strongly dependent on distribution of prey species, particularly small pelagic fish such as capelin and Atlantic herring (Mitchell 1973, Whitehead and Glass 1985). During the early to mid-1990s, in response to abnormally low seawater temperatures, there was a significant redistribution of capelin southward and offshore (Frank *et al*. 1996, Drinkwater 2002). The current distribution of capelin in Newfoundland waters appears to have reverted back to the situation during the 1980s but, when compared to the 1980s, capelin are now less often found in large schools in shallow waters (DFO 2000, 2009). Part of the reported decline in humpback whale entanglements following the 1990s may have therefore been caused by redistribution of preferred prey away from coastal areas. On the basis of recent reports (from fishermen, Coast Guard personnel, and others), humpback whales currently appear less common in inshore waters during summer than in previous years, with more animals sighted in offshore areas.

Interspecies Differences

The results reported here indicate differences in mortality rates between entangled humpback and minke whales. Minke whales were often found dead, whereas humpback whales had a significantly higher chance of survival irrespective of fishing gear involved. Several factors might contribute to this difference. Humpbacks, being larger and stronger than minke whales, were likely able to break through fishing gear more easily and avoid entanglement altogether, and also more likely to be able to reach the surface in the event of a stationary entanglement. In addition, many minke whales were found tightly wrapped up in fishing gear, particularly in gill nets. Minke whales may exhibit similar behaviors to smaller odontocetes such as the harbor porpoise, *Phocoena phocoena*, which has been shown to spin its body along its long axis when attempting to avoid a gill-net entanglement (Kastelein *et al*. 1995); unfortunately, such behaviors often result in animals becoming entangled even further. Release Program staff reported an occasion where a humpback was seen to spin its body in this manner in an attempt to rid itself of an entanglement, which succeeded in breaking free of the gear. Further research is needed to determine the prevalence of such behaviors among baleen whales, and potential mitigating measures that might help prevent such entanglements. While it is possible that this interspecific discrepancy in mortality rates is the result of a bias in the types of entangled minke whales reported (*i.e.*, only the worst cases being reported, as fishermen could themselves deal with less severe entanglements), this seems unlikely given the wide spatial and temporal scope of the data set, and the close working relationships between fishermen and Release Program staff over many years.

Biases

During analysis of entanglement data reported here, several potential problems were identified that could have influenced the results. First among these is the absence of reliable fishing effort data at appropriate spatio-temporal scales. Fishing effort data were not collected consistently for most fisheries in most years; often only landings data exist but typically these are aggregated at a provincial scale. Data on gear types used are also often unavailable, precluding a detailed comparison of gear distribution, and whale entanglement rates in particular areas. Furthermore, landed catch may be a poor measure for estimating total annual entanglement rates; the risk of whale entanglement is more strongly influenced by the amount of gear used and time spent fishing (S. Benjamins, unpublished data).

In the present study, no attempt was made to further subdivide the data set temporally beyond the comparison before and after the 1992 cod moratorium. Rates of reporting are likely to have varied during different phases of the program, however, depending on available funding levels and the state of fisheries at the time. Specifically, lack of resources during 1996–1998 prevented a prompt response to every reported entanglement, and outreach efforts to maintain awareness of the program among fishermen were reduced. This may have resulted in increased mortality rates among entangled whales, more whales released independently by fishermen, and/or fewer whales being reported overall during these years.

There is also the risk of misreporting of entanglements by fishermen who removed the whale without outside assistance, especially in terms of the final fate of the whale, and whether all gear was removed. There is presently no guarantee that fishermen take sufficient care in ensuring that whales are released fully free of gear, with a possible stronger focus on removing the whale from their gear as quickly as possible. A considerable number of animals listed as "Live release" may therefore still have carried pieces of fishing gear with them.

Because no attempts were made to identify entangled whales towing gear, the use of entanglement events as a metric may overestimate the total number of individual whales involved in entanglements, as animals may be reported more than once. This is a particular risk when a whale is released by fishermen while still towing fishing gear, as such an animal might be reported elsewhere later. In this situation, it would be impossible to confirm that both events involved the same animal unless the gear was recovered and identified.

Because of the nature of the Program, not all entanglement events that occurred will have been recorded, particularly those that were comparatively minor and allowed the whale to free itself before being discovered. Conversely, whales that were released alive (or broke free of their own accord) may well have died afterwards from injuries sustained during the entanglement without that fact being recorded. Both of these factors will likely have biased the %Mort values reported here, but there is presently no means of quantifying the extent to which this has occurred.

The Whale Release and Strandings Program data set remains strongly biased toward inshore entanglements. This is largely a result of the way the program was originally set up to cater to the large number of inshore fishermen reporting whale entanglements. Inshore waters, as defined in this study, continue to see the heaviest use overall in terms of number of fishermen; however, since the 1992 moratorium many fishermen have begun fishing further offshore, targeting species such as snow crab. Although an official Fisheries Observer program (overseen by Fisheries and Oceans Canada) is in place for such fisheries, no large whale entanglement has ever been reported to the Release Program through Fisheries Observers. The Release Program has been increasingly active in requesting fishermen to report offshore entanglements. It is not clear how many reports of offshore entanglements described in the present study were filed by fishermen who had recently shifted away from inshore fishing and thus were already familiar with the Release Program. The Release Program does not presently have the logistical ability to provide prompt assistance in all such cases. The risk of financial losses through spoilage of catch already on board may discourage fishermen from seeking assistance through the Release Program, choosing instead to, quite literally, "cut their losses" and release whales themselves; such release attempts may lead to whales continuing to tow significant amounts of gear. In addition, not all such events may subsequently be reported to the Release Program, further biasing the record.

Monitoring and Management

This study has identified large whale entanglement and mortality rates in a range of fisheries over a 30 yr time period, during which the Newfoundland and Labrador fishing industry underwent significant change in intensity, distribution, gear, and target species. The near-continuous operation of the Release Program during this time has allowed some of the impacts of these changes on large whales to be investigated. These results show the relevance of long-term monitoring programs in assessing anthropogenic impacts on large whales. The Release Program has fostered a long term, constructive working relationship between fishermen and the Program, which has encouraged reporting of entangled whales by fishermen without concerns about restrictions placed on them. However, large biases remain in the present Release Program and further efforts are required to provide a clearer picture, particularly in offshore waters. There has also been comparatively little effort put into monitoring large whale survival rates following release from fishing gear, and this should be pursued further in the future.

Reported reductions in large whale entanglements in inshore Newfoundland waters appear to have been driven by a combination of reduced fishing effort, changed licensing conditions, and disappearance or reduction of specific fishing gear types, as well as possible changes to whale distribution and abundance. As such, the reductions in entanglement rates appear to be an indirect consequence of conservation measures aimed at recovery of commercial fish stocks, rather than the result of specific management measures aimed at reducing whale entanglements. Entanglement rates could therefore potentially be reduced even further if additional changes to fisheries were implemented. The two major approaches include area closures and gear modifications, as have already been implemented elsewhere (*e.g.*, the Atlantic Large Whale Take Reduction Plan; NMFS 2010). Particular areas of significance to large whales could be temporarily or permanently closed to certain gear types to reduce the risk of whales encountering gear. Alternatively, modifications to fishing gear and how it is deployed (such as the use of weak links among gear that will break if a whale attempts to escape, or the use of lead rope to reduce the amount of vertical lines in the water column) can reduce the risk of entanglements occurring even when whales encounter gear. However, the relative merits of each of these entanglement reduction approaches are still unclear. Humpback and minke whales are found throughout Newfoundland and Labrador waters but their small-scale distribution remains poorly understood, making it difficult to identify areas where temporal closures might be effective. Given the large geographic scale of the area and the many different fisheries involved in entanglements, encouraging the use of gear modifications might be a more suitable approach to further reduce these entanglement events. However, care must be taken to use approaches that have been proven to actually reduce entanglement risks to large whales while not inadvertently leading to an increase in the number of whales towing comparatively small pieces of gear.

Overall, it appears—perhaps unsurprisingly—that large whale entanglements can be reduced considerably if the fisheries causing these entanglements are closed or significantly curtailed. While entanglement rates of large whales in Newfoundland and Labrador waters have declined significantly since 1992 (primarily due to the removal of cod traps, salmon nets, and an overall decrease in fishing effort), there is a risk that entanglements may rebound in the future. This could be through increased fishing effort in current fisheries (*e.g.*, through eventual recovery of Atlantic cod and other species under moratoria), as well as further development and expansion of emerging fisheries. Given the significant interest in rebuilding commercial fish stocks in Newfoundland and Labrador, any sign of their recovery is likely to be met with calls for quota increases from the industry. The potential impact of any such sudden expansion of fisheries on large whale populations (which themselves are slowly increasing following severe historic exploitation) should be taken into account by marine resource managers wherever possible. Further management measures may be required to prevent entanglements in areas of significant overlap between fisheries and large whale aggregations, particularly in those parts of Newfoundland where whale-watching tourism has recently become an important source of revenue (Hoyt 2001). There is therefore, in Newfoundland and elsewhere, a need to continue moving toward more integrated management of the marine environment and all relevant marine industries, in order to make management decisions at appropriate spatial and temporal scales.

Humpback and minke whale populations in the northwest Atlantic are generally thought to be stable or slowly recovering following historical exploitation (Stevick *et al*. 2003, NMFS 2009). Mortality rates for the Newfoundland humpback whale population were last assessed by Volgenau *et al*. (1995), using entanglement data up to 1992 which indicated that entanglements could have a detrimental effect on population growth. No further studies using post-1992 data have been published so far but, based on preliminary analyses of data presented here, humpback population growth rates do not appear to have been as severely impacted by entanglement-related mortality since the 1992 cod fishery moratorium (S. Benjamins, unpublished data). No comparable information has been published for minke whales. Both humpback and minke whale populations in Atlantic Canadian waters, which include whales in Newfoundland and Labrador waters, are presently listed as "Not at Risk" under Canada's Species At Risk Act (SARA; COSEWIC 2003, 2006), implying that current levels of anthropogenic mortality (including ship strikes and entanglement in fishing gear) are unlikely to lead to significant decline or extinction of this population. This listing status means that, under SARA, no specific management actions to reduce mortality are required within Canadian waters. Whales impacted by entanglements in Newfoundland waters range widely across the north Atlantic during the course of seasonal migrations, and it is important for management authorities to consider all sources of mortality across this extensive range in order to set and achieve meaningful recovery goals for these species. To that end, further collaboration among regional entanglement monitoring programs, in terms of data collection and integration, is essential. The present study provides new information on whale entanglements for an area of considerable significance for large whales in the north Atlantic, which will, it is hoped, influence national and international management decisions impacting these species.

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SUPPORTING INFORMATION

The following supporting information is available for this article online:

Table S1: Summary of all large whale entanglements from 1979 to 2008, stratified by period (pre- *vs.* postcod moratorium), fishing gear, and distance from shore. NB. Figures marked with (*) indicate events where a single whale was entangled in two or even three types of gear. As a result, there are four instances of whales occurring more than once in the table, slightly skewing the sum total (from a total of 1,209–1,212 entanglements).