Influence of anthropogenic activities on marine mammal strandings in the estuary and northwestern Gulf of St. Lawrence, Quebec, Canada, 1994–2008

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ABSTRACT

Stranding records have long been used to monitor marine mammal mortalities and to help identify threats to populations. In coastal areas, marine mammals face numerous anthropogenic threats such as marine traffic and commercial fishing. The objective of this study was to investigate marine mammal stranding records from the St. Lawrence Estuary (SLE) and the northwestern Gulf of St. Lawrence (NWGSL), Quebec, Canada from 1994 to 2008 for evidence of anthropogenic trauma caused by entanglement in fishing gear, ship collisions and gunshots. Of 1,590 marine mammal stranding records, 12% (n = 192) had evidence of anthropogenic trauma, most incidents being reported during summer when activities such as marine traffic, most commercial fishing and recreational boating, occurred and a greater number of species were present in the area. These incidents were classified into five categories (Incidental catch, Ship collision, Severe injury, Gunshot, Other). There were 1,245 mortalities and observations on carcasses suggested that anthropogenic trauma led to the death of 11% (141/1,245) of marine mammals: 14% (87/627) of cetaceans and 9% (54/618) of seals. Mortality of seals due to anthropogenic trauma was low, involving mainly Gunshot for grey (26% or 8/31) and harbour seals (26% or 8/31). Over the study period, marine mammal incidents with evidence of anthropogenic trauma increased significantly, driven by an increase in Incidental catch for two mysticete species, the common minke whale, 42% (39/92) and humpback whale, 13% (12/92) and Other for harbour porpoise 67% (16/24). Ship collision was the most common anthropogenic trauma for fin whales (22% or 8/36) and SLE beluga[5] (22% or 8/36). Severe injury was reported for 22% (2/9) of small cetaceans and 78% (7/9) of seals. Evidence from some harbour porpoise stranding records (categorised as Other) suggests illegal hunting, incidental catch, predation or scavenging by grey seals in a marine protected area. The observed increase in Incidental catch of common minke and humpback whales may be due to: (1) a shift in distribution of these two species into the SLE and NWGSL, possibly related to changes in the ecosystem; (2) changes in fishery practices; and (3) an increase in detection of marine mammal strandings. Anthropogenic trauma affecting marine mammals was documented including some species at risk, such as the harbour porpoise, the St. Lawrence Estuary beluga population, blue and North Atlantic right whales, in the St. Lawrence ecosystem including in a marine protected area. This study demonstrates the usefulness of stranding records in helping to monitor human-caused mortality in marine mammal populations.

KEYWORDS: STRANDINGS; INCIDENTAL CATCHES; TRENDS; ATLANTIC OCEAN; CONSERVATION

INTRODUCTION

Human activities have affected marine mammals over centuries and will likely increase with human population growth, increasing industrialisation of fisheries and maritime traffic (DeMaster *et al.*, 2001). Demand for seafood products and changes in fishery practices led to increased mortality of marine mammals worldwide (Anderson, 2001; Schipper *et al.*, 2008; Reeves *et al.*, 2013; McCauley *et al.*, 2015). Read *et al.* (2006) estimated hundreds of thousands of individual pinniped and cetacean mortalities per year globally due to fishing gear entanglement alone. In addition to incidental catch or entanglement in fishing gear, ship collisions or ship strikes (e.g. Laist *et al.*, 2001; Vanderlaan and Taggart, 2007; Moore *et al.*, 2013; Hill *et al.*, 2017), gunshots (e.g. Goldstein *et al.*, 1999), noise (e.g. Nowacek *et al.*, 2007) and loss and degradation of habitat (e.g. Kemp, 1996; Harwood, 2001) can adversely affect marine mammals. As Read (1996) noted, in many ecosystems, there is insufficient understanding of the effects of human activities on marine mammals due to a lack of information on these activities (e.g. frequency and intensity of commercial fishing) and/or on the dynamics of marine mammal populations (e.g. distribution, abundance and mortality).

Although marine mammal stranding data are limited by condition of carcasses, operational logistics and efficiencies of stranding networks, stranding data can provide insights into population dynamics, threats to survival and trends over time (e.g. Leeney *et al.*, 2008; Johnston *et al.*, 2012; Truchon *et al.*, 2013). Recent studies using stranding data to examine mortalities associated with human activities demonstrate the value of these data as indicators of anthropogenic trauma caused by, for example, incidental catch (e.g. Lopez *et al.*, 2002; Kemper *et al.*, 2005; Byrd *et al.*, 2008; Bogomolni *et al.*, 2010). The availability of a multi-year stranding dataset with extensive monitoring offers opportunities to document the effects of human activities on marine mammals in a systematic and rigorous manner over large time and spatial scales and for numerous species (Byrd *et al.*, 2008).

The St. Lawrence Estuary and the Gulf of St. Lawrence are two important feeding areas for marine mammals of the North Atlantic in summer (Sourisseau *et al.*, 2006; Simard, 2008). While some species, are year-round residents, i.e. the

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St. Lawrence Estuary beluga (*Delphinapterus leucas*) and harbour seal (*Phoca vitulina*), others are seasonal visitors, i.e. grey seal (*Halichoerus grypus*) in summer and pagophilic harp (*Pagophilus groenlandicus*) and hooded (*Cystophora cristata*) seals in winter. A diversity of large whales migrate to these areas in summer (Kingsley and Reeves, 1998) resulting in a well-developed whale watching industry (Lien, 2001; Parrott *et al*., 2011). This activity combined with marine traffic (Blane and Jackson, 1994; Lesage *et al.,* 1999; Henry and Hammill, 2001) and commercial fisheries are threats to resident and seasonal marine mammal populations of this ecosystem.

There are a few studies reporting marine mammal mortalities associated with anthropogenic activities in the St. Lawrence ecosystem (Béland *et al.,* 1987; Béland *et al.,* 1992; Nemiroff *et al*., 2010) including, for example, incidental catch of harbour porpoises (*Phocoena phocoena*) in groundfish gillnets through at-sea observer programs (Fontaine *et al.,* 1994; Lesage *et al.,* 2006). However, little information is available on the effects of other activities such as ship collisions and illegal shooting with guns) on marine mammals in the SLE, GSL and in the Saguenay-St. Lawrence Marine Park (SSLMP), a national marine protected area. Some species may be especially at risk such as the St. Lawrence Estuary beluga population, blue whale (*Balaenoptera musculus*) and North Atlantic right whale (*Eubalaena glacialis*), all of which have Endangered status under Canada's Species at Risk Act[6]. Anthropogenic activities have deleterious effects on these populations (Hammill *et al.,* 2007; Chion *et al*., 2017).

The objective of this study is to examine a stranding dataset for evidence of anthropogenic trauma and of mortalities due to anthropogenic trauma, to identify which activities are involved and to study temporal variations in marine mammal incidents associated with these activities in the St. Lawrence Estuary and northwestern Gulf of St. Lawrence over a 15-year study period (1994 to 2008).

METHODS

Study area

The study area (Fig. 1) includes the St. Lawrence River, the St. Lawrence Estuary (SLE) and the northwestern part of the Gulf of St. Lawrence (NWGSL)[7]. The SLE and the NWGSL have important physical and oceanographic features (tidal interactions with bathymetry, wind-driven upwelling and circulation) that favour recurrent aggregations of prey, and thus are important feeding grounds for various marine mammal species in summer (Sourisseau *et al.,* 2006; Simard, 2008). The SLE is especially important in the conservation

[6] *http://www.sararegistry.gc.ca.*
[7] Northwest Atlantic Fisheries Organisation (NAFO) (Divisions 4S, 4R and part of 4T) in Quebec.

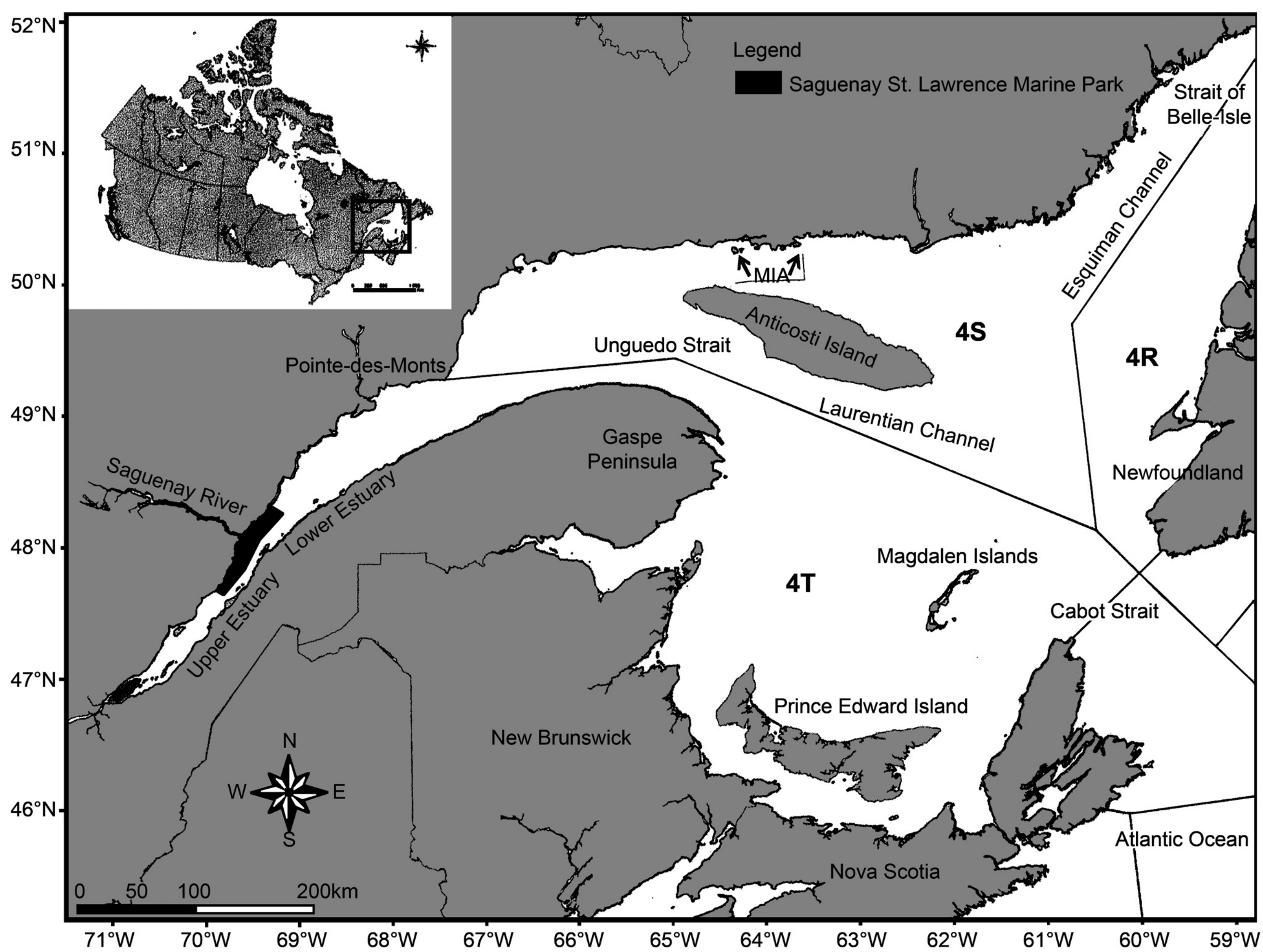

Fig. 1. Study area including the St. Lawrence Estuary, Gulf of St. Lawrence and Saguenay-St. Lawrence Marine Park. Arrows indicate location of Mingan Island Archipelago (MIA).

of resident and seasonal marine mammals (at least 12 species) and was identified as ecologically and biologically significant for these marine animals (Lesage *et al.,* 2007). In 1998, the first national marine protected area in eastern Canada, the Saguenay-St. Lawrence Marine Park (SSLMP), located at the confluence of the Saguenay River and the SLE and covering over 1,245 km^2 of sea surface, was created. The St. Lawrence ecosystem is also used for commercial activities including ecotourism, fisheries and marine transportation (Blane and Jackson, 1994; Henry and Hammill, 2001; Parrott *et al*., 2011). A well-developed whale watching industry operates during the summer in the SSLMP (Lien, 2001) as well as around the Gaspé peninsula, and the Mingan Island archipelago. Several commercial fisheries occur in the St. Lawrence ecosystem including for Greenland halibut (*Reinhardtius hippoglossoides*), herring (*Clupea harengus*) and capelin (*Mallotus villosus*) using gillnets and traps, and for waved whelks (*Buccinum undatum*), rock crab (*Cancer irroratus*), snow crab (*Chioneocetes opilio*) and northern lobster (*Homarus americanus*) using pots (MAPAQ, 2008; DFO, unpublished data).

Data collection

Two marine mammal stranding datasets collected over a 15-year period by Fisheries and Oceans Canada (DFO) were combined, from 1994 to 2002, and by the marine mammal emergency network, Réseau québécois d'urgences pour les mammifères marins (RQUMM), from 2003 to 2008. The emergency network was co-ordinated by a non-governmental organisation, Groupe de recherche et d'éducation sur les mammifères marins (GREMM). The datasets were systematically analysed, extracting information on incidents involving human activities. Geraci and Lounsbury (2005) defined a stranding as a marine mammal coming ashore sick, weak or dead with a mass stranding involving at least two animals ashore at the same place and time (except for cases involving a female and her calf). Reports of fishery entangled marine mammals were included (alive or dead) occurring offshore in fixed fishing gear (i.e. nets, traps and pots), animals which may not necessarily strand later on shore. Numbers of strandings were used as the sampling unit for analysis and not the number of animals involved in each stranding, either single or mass strandings, to minimise bias and over-estimation. Analysis of stranding data included only those cases where identification of marine mammal species was based on verifiable criteria (pictures and/or a reliable observer). Ambiguous cases of identification and equivocal reports of strandings were excluded from analyses. Carcasses for necropsy were selected based on their condition, size and accessibility, and operational logistics. Necropsies were performed by experienced biologists (DFO) or veterinary pathologists (Faculty of Veterinary Medicine, Université de Montréal, Saint-Hyacinthe, Québec). Mortalities associated with human activities were based on necropsy results or gross observations of carcasses showing evidence of anthropogenic trauma (see definition of five categories below).

Marine mammal strandings with evidence of trauma from direct anthropogenic activities were classified into the five categories below based on specific definitions from the literature.

(1) **Incidental catch** or by-catch: defined as incidental capture in fishing gear of non-target species which are discarded at sea, dead (or injured such that death results) (Alverson *et al.,* 1994; Moore *et al*., 2013), including observations of unhealed, narrow, linear lacerations or indentations in the epidermis, most commonly observed around the head, dorsal fin, flukes and flippers (Read and Murray, 2000), fishing gear on animals and release of live entangled animals.

(2) **Ship collision**: defined as an impact of a vessel and a live marine mammal with sufficient force to result in physical trauma (bone fracture with ante-mortem haemorrhage) resulting in death (Laist *et al.,* 2001; van Waerebeek *et al.,* 2007). This category included propeller strikes as indicated by helical cuts at regular intervals on carcasses (Read and Murray, 2000; Pugliares *et al*., 2007).

(3) **Severe injury** or serious injury: defined as injuries related to human activities but not diagnostic of entanglement in fishing gear, ship collision or gunshot, an injury more likely than not to result in mortality (Moore *et al*., 2013). This category includes observations of straight-edge cut marks on carcasses consistent with cuts made by an instrument such as a knife, including appendages cleanly removed or other mutilations (Read and Murray, 2000; Pugliares *et al*., 2007).

(4) **Gunshot**: defined as the presence of a bullet in vital organs (liver, heart, brain, etc.) observed at a gross necropsy or penetrating circular wounds on a carcass consistent with a gunshot (see Read and Murray, 2000; Moore *et al*., 2013).

(5) **Other**: defined as evidence of anthropogenic trauma that does not fit the above four definitions or that has more than two different categories of trauma. In this study large pieces (approximately 20cm × 30cm) of harbour porpoise skin and blubber were found floating in the SSLMP without the rest of the carcass, pieces had straight-edge cut marks consistent with cuts made by an instrument such as a knife. These pieces were collected by SSLMP personnel when found and each observation with collection of pieces was counted as one report.

Carcasses too decomposed or with severe scavenger damage [irregular, multiple, shallow scrapes particularly around the head, anus or umbilicus (see Read and Murray, 2000)] precluding an adequate evaluation of the anthropogenic trauma category involved were excluded.

Statistical analyses

All statistical tests were conducted with R.2.8.0 (R Development Core Team, 2008). Marine mammal strandings with evidence of anthropogenic trauma were separated by marine mammal group (i.e. large cetaceans, small cetaceans and seals) including live (entanglements) and dead animals. Linear and polynomial regressions were performed to model inter-annual variations in anthropogenic trauma. Logarithm transformations were applied when data were not normally distributed and the homogeneity of variance was not respected (Zar, 1999). A P value <0.05 was considered statistically significant.

Table 1

Number (N) and proportion (%) of mortalities with evidence of anthropogenic trauma (AT) by category from 1994 to 2008 in Québec, Canada.

	Categories of anthropogenic trauma (N, % of total dead)					Cause of death (COD) N		
Group	Incidental catch	Gunshot	Ship collision	Severe injury	Other	Total AT	Other COD	N dead
All marine mammals	54 (4.3%)	31 (2.5%)	28 (2.2%)	8 (0.6%)	20 (1.6%)	141 (11.3%)	1,104 (88.7%)	1,245
All seals	12 (1.9%)	30 (4.9%)	3 (0.5%)	6 (1.0%)	3 (0.5%)	54 (8.7%)	564 (91.3%)	618
All cetaceans	42 (6.7%)	1 (0.2%)	25 (4.0%)	2 (0.3%)	17 (2.7%)	87 (13.9%)	540 (86.1%)	627
Small cetaceans*	5 (1.2%)	1 (0.2%)	12 (2.9%)	2 (0.5%)	15 (3.5%)	35 (8.3%)	385 (91.7%)	420
Large cetaceans*	30 (19.4%)	–	13 (8.4%)	–	1 (0.6%)	44 (28.4%)	111 (71.6%)	155

*Excludes 52 unidentified cetaceans of which 8 (15.4%) died due to anthropogenic trauma and 44 (84.6%) died of other causes.

Table 2

Reports of marine mammal strandings (live and dead) with evidence of anthropogenic trauma (AT) by category from 1994 to 2008 in Québec, Canada.

	Categories of anthropogenic trauma (AT)												
	Incidental catch		Gunshot		Ship collision		Severe injury		Other				
Species	N[1]	%[2]	N[1]	%[2]	N[1]	%[2]	N[1]	%[2]	N[1]	%[2]	Total AT N[1]	%[3]	N Dead
Large cetaceans													
Balaenoptera acutorostrata	39	42.4	–	–	8	22.2	–	–	–	–	47	24.5	101
Balaenoptera physalus	3	3.3	–	–	8	22.2	–	–	–	–	11	5.7	36
Balaenoptera musculus	2	2.2	–	–	–	–	–	–	–	–	2	1.0	7
Megaptera novaeangliae	12	13.0	–	–	–	–	–	–	1	4.2	13	6.8	4
Eubalaena glacialis	3	3.3	–	–	–	–	–	–	–	–	3	1.6	2
Physeter macrocephalus	–	–	–	–	1	2.8	–	–	–	–	1	0.5	5
Subtotal	59	64.1	–	–	17	47.2	–	–	1	4.2	77	40.1	155
Small cetaceans													
Phocoena phocoena	5	5.4	1	3.2	5	13.9	1	11.1	16	66.7	28	14.6	170
Delphinapterus leucas	3	3.3	–	–	8	22.2	–	–	–	–	11	5.7	222
Lagenorhynchus acutus	–	–	–	–	–	–	1	11.1	–	–	1	0.5	28
Subtotal	8	8.7	1	3.2	13	36.1	2	22.2	16	66.7	40	20.8	420
Unidentified cetacean	11	12.0	–	–	3	8.3		–	–	–	14	7.3	52
Subtotal cetaceans	78	84.8	1	3.2	33	91.7	2	5.6	17	70.8	131	68.2	627
Seals													
Phoca vitulina	6	6.5	8	25.8	–	–	2	22.2	1	4.2	17	8.9	92
Halichoerus grypus	3	3.3	8	25.8	1	2.8	–	–	–	–	12	6.3	93
Pagophilus groenlandicus	–	–	5	16.1	1	2.8	2	22.2	1	4.2	9	4.7	42
Cystophora cristata	1	1.1	1	3.2	1	2.8	1	11.1	1	4.2	5	2.6	63
Unidentified seal	4	4.3	8	25.8	–	–	2	22.2	4	16.7	18	9.4	328
Subtotal seals	14	15.2	30	96.8	3	8.3	7	77.8	7	29.2	61	31.8	618
Total	92	47.9	31	16.1	36	18.8	9	4.7	24	12.5	192	100	1,245

N[1] = number. %[2] = percentage of the total in the AT category for the specified species or group of species, i.e. 39/92 or 42.4% for *B. acutorostrata*, Incidental catch. %[3] = percentage of the 192 total AT incidents for the specified species or group of species, i.e. 47/192 or 24.5% for *B. acutorostrata* Total AT.

RESULTS

Of the 1,590 marine mammal stranding records, 1,245 reported dead animals (Table 1). Observations on carcasses suggested that anthropogenic trauma led to the death of 11% (141/1,245) of marine mammals: 14% (87/627) of cetaceans and 9% (54/618) of seals (Table 1). Other causes of death (89%, 1,104/1,245) involved infections, neoplasia, reproductive problems (dystocia, neonatal separation or abandonment), harmful algal blooms, or no cause was determined. Of the 192 marine mammal incidents with evidence of anthropogenic trauma, 51 involved animals that apparently survived (escaped, were freed from nets or their fate was unknown). Fatal anthropogenic traumas were reported more often for large (28% or 44/155) than small (8% or 35/420) cetaceans involving most often Incidental catch (19% or 30/155) and Other (3.5% or 15/420), respectively, followed by Ship collision (8% or 13/155 for large cetaceans and 3% or 12/420 for small cetaceans). Although there was no evidence of Gunshot for cetaceans (except one incident reported for harbour porpoise), this category was the most common fatal anthropogenic trauma identified for seals (5% or 30/618).

Of a total number of 1,590 marine mammal stranding records (live and dead) recorded from 1994 to 2008, 12% or 192 had evidence of anthropogenic trauma (Table 2): 92 were categorised as Incidental catch (48%), 31 categorised as Gunshot (16%), 36 categorised as Ship collision (19%), 9 categorised as Severe injury (5%) and 24 categorised as Other (13%) and involved 6 species of large cetaceans, 3 species of small cetaceans and 4 species of seals. The common minke whale (*Balaenoptera acutorostrata*) had the greatest number of records of anthropogenic trauma, 25% or 47/192, mostly Incidental catch (39/47), of which 28% or 11/39 involved invertebrate pots, 3% or 1/39 involved gillnets, or the type of fishing gear was not determined by observers, 69% or 27/39.

Species and groups differed in the number of records having evidence of anthropogenic trauma (Table 2). Incidental catch was most commonly reported for large cetaceans. Ship collision was reported mostly for fin whales (*Balaenoptera physalus*; 22% or 8/36) and common minke whales (22% or 8/36). Incidental catch was also reported for two endangered blue and three North Atlantic right whales. In the small cetacean group, Ship collision was most commonly reported for SLE beluga (22% or 8/36), while harbour porpoise strandings were reported mostly as Other (67% or 16/24) and in the SSLMP only. Gunshot was almost exclusively reported in seals (97% or 30/31) compared to other stranded marine mammals, with primarily grey seals (26% or 8/31) and harbour seals (26% or 8/31) found with evidence of gunshot.

Overall, reports with evidence of anthropogenic trauma in marine mammals increased during the summer months (Fig. 2) and over the study period (1994–2008). The number of reports reached a maximum in 2005 and since 2006, declined to around 12 reported per year (Fig. 3a). This annual trend is positively correlated with Incidental catch ($R^2_{adj.} = 0.47$, $F_{2,12} = 7.22$, $p = 0.009$) and Other ($R^2_{adj.} = 0.45$, $F_{1,13} = 12.44$, $p = 0.004$), which also increased during the study period (Fig. 3b). Incidental catch was mostly reported in NAFO Division 4T (63%) and involved common minke whale ($R^2_{adj.} = 0.80$, $F_{1,1} = 51.49$, $p < 0.001$) (Fig. 4a) and humpback whales (*Megaptera novaeangliae*) ($R^2_{adj.} = 0.22$, $F_{1,13} = 5.0$, $p = 0.04$) (Figs 4b). Other involved only the harbour porpoise ($R^2_{adj.} = 0.87$; $F_{1,14} = 97.97$; $p < 0.001$) (Fig. 4c). Other categories (i.e. Severe injury, Ship collision and Gunshot)

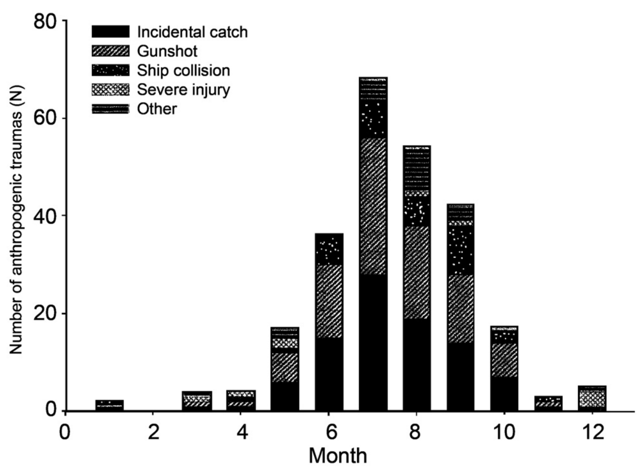

Fig. 2. Seasonal variability in the number of incidents with evidence of anthropogenic trauma for live and dead marine mammals in Québec (1994 to 2008).

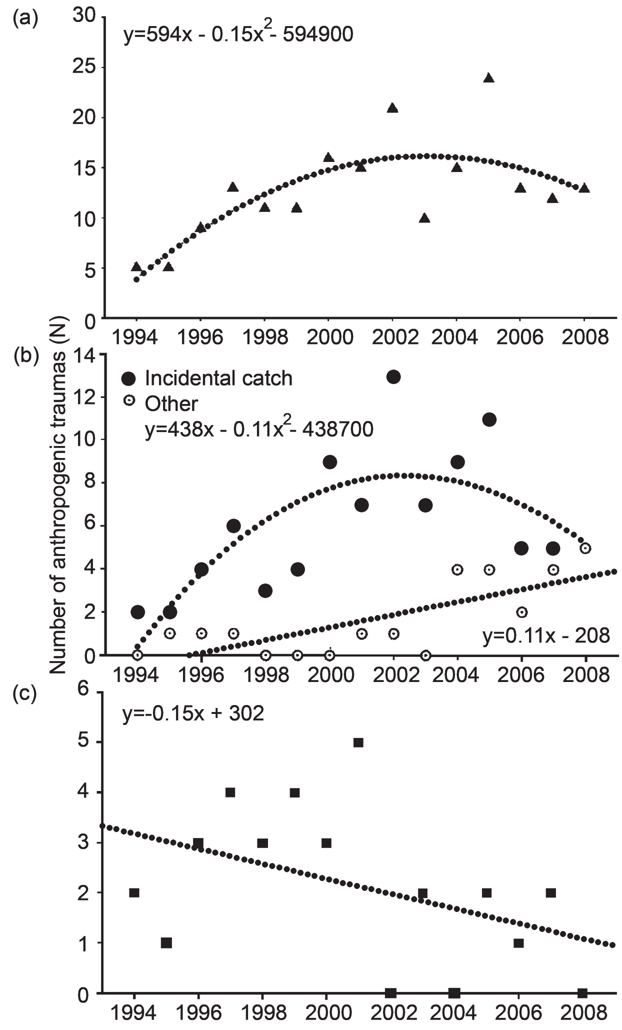

Fig. 3. Inter-annual variability in the number of live and dead marine mammals with evidence of anthropogenic trauma: (a) all categories, (b) Incidental catch (black circles) and Other (open circles), (c) Gunshot.

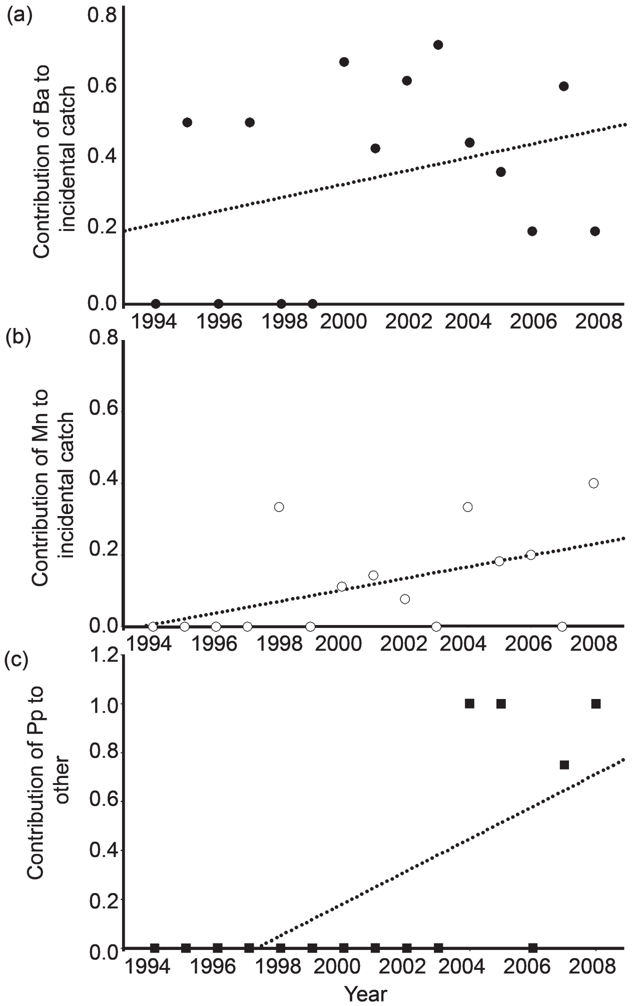

Fig. 4. Contribution of live and dead minke whale, Ba (a), and humpback whale, Mn (b) of all incidents of Incidental catch, and contribution of harbour porpoise, Pp, to Other (c) in Québec (1994–2008).

remained relatively constant over time, however, a decreasing trend was noticed in the number of reports for seals with evidence of GUNSHOT since 2002 (Fig. 3c).

DISCUSSION

Based on stranding records, an estimated 12% of marine mammal strandings had evidence of trauma due to anthropogenic activities, primarily INCIDENTAL CATCH (48%). Evidence from carcasses indicated that 11% of marine mammals died as a result of anthropogenic activities with INCIDENTAL CATCH involved in the largest numbers of deaths, particularly for large cetaceans (19% of 155 deaths). Béland *et al.* (1992), in a study with similar methodology, reported 31% (35/113) of marine mammal strandings for the period 1988 to 1990 in the SLE and GSL, for which a cause of death could be determined, died due to anthropogenic activities (21% or 18/85 cetaceans and 61% or 17/28 seals), the remaining 78 other marine mammals died of disease or parasitism. In the Canadian Maritime provinces, Nemiroff *et al.* (2010) with similar methodology to this study, reported 11% cetaceans involved in fishing gear entanglements for the period 1990 to 2008, particularly harbour porpoise and mysticetes. These studies as well as ours indicate that cetaceans are vulnerable to fishing gear in the St. Lawrence ecosystem. A variety of biological factors can influence incidental catch of marine mammals such as species distribution, behavioural traits (curiosity, exploration, social patterns and feeding activities) (Fertl and Leatherwood, 1997; Morizur *et al.,* 1999), sensory capacities and attention (Perrin *et al.,* 1994). Feeding activities may increase vulnerability to entanglement and may be an important component in many incidental catches (Lien, 1994; Fertl and Leatherwood, 1997). The patchiness of marine resources, high feeding requirements and energetic costs of feeding strategies can make feeding areas with fishing activities, such as the SLE and GSL, attractive to marine mammals, particularly mysticetes (Piatt and Methven, 1990; Doniol-Valcroze *et al.,* 2007; Vanderlaan *et al.*, 2011; Cassoff *et al*., 2011).

Although large whales seem to be more vulnerable to human activities in the SLE and NWGSL than other marine mammals, seals may be under-represented in the stranding database. Large cetaceans, due to their size, visibility and popularity with the public, are more likely to be reported when stranded than small cetaceans and seals. In cetacean strandings, more cetaceans could be identified to species (89% or 117/131) based on descriptions by observers, examination of carcasses or photographic evidence than seals (70% or 43/61).

In the SLE and NWGSL there are more human activities such as recreational boating, whale watching, marine traffic and commercial fisheries in summer and early fall than in other seasons when cold temperatures, snow and ice can preclude some outdoor activities. In addition, strandings are more likely to be reported when observers are present and active. Seasonality of incidents involving human activities was documented by other workers (Beland *et al*., 1987; Nemiroff *et al.,* 2010) and is also a function of seasonal migration and movement of marine mammals (Lopez *et al.,* 2002; Byrd *et al.,* 2008; Bogomolni *et al.,* 2010). In this study area, most species migrate to the SLE and NWGSL during summer to early fall to forage (Edds and MacFarlane, 1987; Lavigueur *et al.,* 1993; Kingsley and Reeves, 1998). A high number of incidental catches of harbour porpoises in early fall may be associated with their inshore movements in response to increased abundance of prey (Lesage *et al*., 2006). Therefore, reports with evidence of anthropogenic trauma on stranded marine mammals are likely a function of seasonal abundance, movements and intensity of human activities, factors occurring for most species during summer in this study area.

Seals

All marine mammal strandings but one (a harbour porpoise) in the Gunshot category involved seals, with grey seals and harbour seals most commonly found dead with evidence of gunshot. Béland *et al*. (1992) observed 65% (11/17) of seals dead due to gunshot, 24% (4/17) of seals due to entanglement in fishing gear and 12% (2/17) due to collision. Shooting is the most common anthropogenic cause of mortality for pinnipeds (Stroud and Roffe, 1979; Béland *et al.,* 1987; Béland *et al.,* 1992; Goldstein *et al.,* 1999). In this study area, Gunshot occurred mostly in summer, a period when the SLE is closed to hunting (Lesage and Hammill, 2001). The harbour seal is a species protected from hunting in eastern Canada and the grey seal is protected in the SLE during summer (Lesage *et al.,* 2007; COSEWIC, 2007). Commercial fishers have a negative perception of seals as they cause considerable damage to fishing gear and remove target fishery species resulting in financial losses (Beddington *et al.,* 1985; Lesage *et al.,* 2001). The abundance of grey and harbour seals in the SLE (Lavigueur *et al.,* 1993) and the increasing grey seal population of the North Atlantic (DFO, 2014a) may bring a large number of seals into conflict with the fishing industry increasing the probability of death due to gunshot and fishing gear entanglements.

Cetaceans

Incidental catch is the most common fatal anthropogenic trauma in small cetaceans worldwide, especially for porpoises and dolphins (Lesage *et al.,* 2006; Read, 2008). Béland *et al.* (1992) observed 83% (15/18) of cetaceans dead due to entanglement in fishing gear with three possible deaths due to collision, neither involving small cetaceans such as harbor porpoise. In this study, the main anthropogenic trauma for harbour porpoises was Other. This consisted of pieces of skin and blubber (approximately 20 × 30cm) from harbour porpoises found floating within a nautical mile of shore near Grandes-Bergeronnes or Les Escoumins, municipalities located on the north shore of the SLE within the SSLMP. These 'pieces' were described as having straight-edge cut marks that appeared consistent with cuts made by an instrument such as a knife. Conservation officers of the SSLMP who found these tissues suspected illegal hunting of harbour porpoises but investigations failed to identify the source (Parks Canada, SSLMP, Tadoussac, pers. comm.). Possible mutilation of harbour porpoises caught in fishing gear as some fishers reportedly do, in order to facilitate disentanglement of by-caught marine mammals and to protect gear (Read and Murray, 2000; Byrd *et al*., 2008), was not suspected as commercial fisheries in the area are low to nonexistent. Carcasses or pieces of carcasses may drift within the SLE with tidal fronts, winds and gyres (Saucier *et al*., 2009). These porpoise 'pieces' as described above were first observed in 2004, however, dorsal or pectoral fins, viscera and skin and blubber from the flank, abdomen and dorsum were also found in subsequent years. In 2013, near Tadoussac in the SSLMP, a grey seal was observed and photographed tearing pieces of skin and blubber from a fresh harbour porpoise carcass (R. Michaud, GREMM, pers. comm.). Blood was observed in the surrounding water with some floating pieces of skin and blubber. One piece was collected and photographed. The edges of skin appeared straight or curved but irregular on closer examination, not as one might attribute to knife-cuts. The skin bore tooth or claw punctures and the blubber had loose fibers likely caused by the seal ripping and tearing pieces of flesh from the porpoise using their teeth and holding or pushing the carcass with their claws. It was unknown whether the grey seal had killed the porpoise or was scavenging a fresh carcass. Evidence of similar scavenging and predation on harbour porpoises or harbour seals has been documented in Europe (Haelters *et al.,* 2012; Jauniaux *et al*., 2014; van Bleijswijk *et al*., 2014; Bouveroux *et al*., 2014; Leopold *et al*., 2015a, b; Stringell *et al.,* 2015). Haelters *et al*. (2012) described 'ragged edges' on harbour porpoise blubber torn by a grey seal. In Canada, Great white (*Carcharodon carcharias*) and Greenland (*Somniosus microcephalus*) shark attacks on harbour seals leave different marks on carcasses (Lucas and Natanson 2010). In the SLE the Great White shark is absent but the endemic Greenland shark (Stokesbury *et al.,* 2005) may be a predator or scavenger of marine mammals but unlikely to be the source of the porpoise 'pieces' reported here (van den Hoff and Morrice 2008). It could not be confirmed whether porpoise 'pieces' found prior to 2013 result from illegal hunting or incidental catch or, alternatively, from predation or scavenging by grey seals. Grey seals also cannibalise grey seal pups (Bedard *et al*., 1993) and harbour seals (van Neer *et al*., 2015) and, with increasing grey seal abundance in eastern Canada, monitoring of interactions between harbour porpoises and grey seals is warranted.

Ship collision was the second most frequent anthropogenic trauma reported for cetaceans, involving mostly common minke, fin whale and the SLE beluga. Ship collisions are probably under-reported for rorquals as they tend to sink after death (Bonner, 1989) and carcasses may not refloat if pressure at depth in the Laurentian Channel (400m) exceeds pressure from gaseous decomposing carcasses. Bottom currents in the SLE are upstream at depth (Saucier *et al.,* 2009) precluding sunken carcasses from drifting out of the Channel. Incidental catch and ship collision are not considered significant causes of mortality threatening the SLE beluga population (Hammill *et al.,* 2007). Lair *et al.* (2016) reported 8 (4%) and 2 (1%) mortalities due to ship/boat collision and incidental catch, respectively, of 222 SLE beluga examined at necropsy for the period 1983 to 2012. Nevertheless, even these few cases of incidental catch and ship collision mortalities in addition to other factors, such as degradation and loss of habitat, chemical and biological contamination, infections, diseases, noise, disturbance (maritime traffic and whale-watching) and harmful algal blooms, likely contribute to the lack of recovery of this population (Lesage *et al.,* 1999; Truchon *et al*., 2013; DFO, 2014b; Lair *et al*., 2016; Starr *et al*., 2017).

Incidental catch was the principal anthropogenic trauma for large whales in the SLE and the NWGSL, involving primarily common minke whales followed by humpback whales as also observed by Béland *et al.* (1992). Lien (1994) also reported higher numbers of entanglements of common minke whales in fishing gear than humpback whales in Newfoundland and Labrador. In this study, the increase of Incidental catch (live and dead), mostly in NAFO Division 4T, is probably not due to increased public awareness and detection effort since 1994. Variations in Incidental catch, particularly for common minke and humpback whales, suggest that ecological processes (e.g. shifts in distribution) may be involved. Three hypotheses are suggested to explain this increase: (1) shifts in distribution of common minke and humpback whales, (2) changes in fishery practices; and (3) an increase in detection of marine mammal strandings.

In the SLE and NWGSL, rorquals are associated with aggregations of prey (e.g. krill, capelin) and, consequently, are particularly likely to be in the same areas as commercial fishery activities (Sourisseau *et al.,* 2006; Doniol-Valcroze *et al.,* 2007; Simard, 2008). The inshore abundance of humpback whales, which was correlated with the abundance of capelin (an important prey), probably resulted in high numbers of entanglements in the inshore fishery off eastern Newfoundland from 1977 to 1980 (Whitehead and Carscadden, 1985). Similarly, in the NWGSL, Comtois *et al.* (2010) reported an increase in the number of humpback whale sightings as well as a change in their geographical distribution. They suggested an association between this change in distribution and changes in oceanographic features (cold sea bottom temperature) and faunal community structure (the collapse of demersal fish predators from overfishing in the late 1980's and early 1990s) (Savenkoff *et al.,* 2007; Morissette *et al.,* 2009). Overfishing of groundfish is also suspected to have contributed to significant geographic expansion in the distribution of capelin in the mid 1990s throughout the entire Gulf, particularly in Division 4T (Grégoire *et al.,* 2008) due to the collapse of its major predator, the Atlantic cod (Carscadden *et al.,* 2001). In recent years, the expansion in the distribution of capelin in the SLE and southern GSL is likely to attract foraging common minke and humpback whales leading to increased incidental catches recorded in Division 4T. However, this proposed hypothesis should be considered with caution as there is little data on the distribution of rorquals and capelin and no capelin abundance data in the SLE and NWGSL and the incidental catch data were obtained from reported strandings only.

Alternatively, the increase in incidental catch may be due to changes in fishery practices in recent years. Following the groundfish collapse in the early 1990s, the number of groundfish landings decreased while the number of invertebrate landings increased (Benoît *et al*., 2012). Few fisheries are authorised in the SLE in summer and most involve fisheries for waved whelks and crabs. Traps and pots used to catch benthic species (i.e. whelks, crabs, lobsters and dogfish) are known to pose a high risk of entanglement for large whales in the Bay of Fundy (Johnston *et al.,* 2007). In this study area, common minke whale entanglements occurred mostly with invertebrate traps. Some common minke and humpback whales observed swimming with invertebrate trap lines become exhausted, immobilised and die in severe cases.

This study is limited by the nature of stranding data and detection effort such that the stranding data are not representative random samples of populations; monitoring thousands of kilometres of coastlines requires extensive logistics with associated costs, as well as trained observers and experts to perform necropsies, both of which are often limited leading to under-reporting of strandings and limited potential for determination of cause of death (Lopez *et al.,* 2002; Nemiroff *et al*., 2010). As a consequence, the data likely underestimates the effect of human activities on marine mammals. Despite these limitations, stranding data are a useful tool in identifying threats to marine mammal species (DFO, 2007; Truchon *et al*., 2013; Mosnier *et al*., 2015). Long-term stranding data should be combined with other more direct management measures and incorporate uncertainty in analysing human-induced mortality (Wade, 1998; Hammill and Stenson, 2009). However, such analyses require estimates of population abundance (current, pristine or pre-exploitation) and population growth rates which are lacking or incomplete for most species in this study area. Nevertheless, the data suggest that effects of maritime traffic (ship collisions), fisheries (entanglement in fishing gear), gunshot, possible predation and illegal hunting of some species, especially those at risk, may be an important limiting factor for some marine mammal populations in the SLE and NWGSL.

CONCLUSION

The data obtained provide a long time-series on multiple species that is a useful source of information on human activities affecting marine mammals in the SLE and NWGSL, an ecosystem intensively used by humans. An analysis was presented of temporal trends of anthropogenic traumas on marine mammal species confirming that these incidents occur mostly in summer and are of concern for some species; i.e. shooting of Atlantic harbour seals (not at risk: COSEWIC, 2007), possible illegal hunting of Northwest Atlantic harbour porpoise (Special Concern status: COSEWIC, 2006) in a marine protected area (SSLMP) and ship collisions and incidental catches of endangered SLE beluga. Although not included in the analyses due to low numbers, these data show that endangered blue whales and North Atlantic right whales are also at risk from fishing gear in this study area. A general decline in fatal incidental catches of large cetaceans in the study area over the past six years of this study may be due to the disentanglement assistance program initiated by RQUMM and other non-governmental organisations with commercial fishers. Similar assistance programs have proven successful in the Bay of Fundy and coastal New England (Mayo *et al.,* 1998; Moore *et al*., 2010) and Newfoundland and Labrador (Lien, 1994). These programs involve training or assisting fishers to disentangle and free marine mammals from fishing gear or employ experienced and specially trained disentanglement teams. Management measures to reduce ship collisions, e.g. through regulated reduced ship speed, volunteer exclusion areas, conservation areas, changes in navigation routes, on-board observers, and to reduce incidental catch through e.g. use of modified fishing gear, acoustic alarms, time-area fishery closures or public outreach and education, show mixed results in reducing some of these sources of mortality for some cetacean populations (Cox *et al*., 2007; Trippel *et al*., 2008; Vanderlaan *et al.,* 2008; Vanderlaan and Taggart, 2009; Read, 2013). Within the SSLMP, vessel speed is regulated at 25 knots maximum with reduction to 15 knots at the mouth of the Saquenay River[8]. However, more effort and research to reduce mortalities significantly due to human activities are required, especially in eastern Canadian waters (van der Hoop *et al*., 2012; Chion *et al*., 2017; Brillant *et al*., 2017), and should include monitoring to document effects of mitigation.

The findings here indicate the need for more information to evaluate threats to marine mammals in this study area: i.e. data on abundance and distribution of marine mammal species and important prey such as capelin (Carscadden *et al.,* 2001; Bundy *et al.,* 2009), and information on the location and type of fishing gear used and species involved in incidental catch. Future research will be crucial in identifying problems requiring management measures to mitigate the effect of human activities on marine mammals,

[8] *www.parcmarin.qc.ca/protect.*

particularly in areas identified as ecologically and biologically significant for marine mammal populations of the North Atlantic such as the Saguenay-St. Lawrence Marine Park.

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