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Using bycatch data to understand habitat use of small cetaceans: lessons from an experimental driftnet fishery

Garry B. Stenson [1]*, Steven Benjamins [2], and David G. Reddin [1]

[1] *Science Branch, Department of Fisheries and Oceans, St John's, NL, Canada A1C 5X1*
[2] *Scottish Association for Marine Science, Oban, Argyll and Bute PA37 1QA, Scotland, UK*

**Corresponding Author: tel: +1 709 7227152; fax: +1 709 7724188; e-mail: garry.stenson@dfo-mpo.gc.ca.*

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Many marine mammals inhabit offshore areas where it is difficult to determine distribution and abundance. Historical bycatch data of marine mammals in the Northwest Atlantic obtained from the Canadian experimental Atlantic salmon (*Salmo salar*) driftnet fishery were examined to obtain information on seasonal distribution and relative abundance. From 1965 to 2001, 47 cruises were undertaken totalling 12 566.5 km-h of fishing effort; four species of small cetacean and two species of pinniped were caught. Harbour porpoises (*Phocoena phocoena*) were the most frequently caught species in all areas except the Labrador Sea, where Atlantic white-sided dolphins (*Lagenorhynchus acutus*) were more common. Long-finned pilot whales (*Globicephala melas*), common dolphins (*Delphinus delphis*), harp seals (*Pagophilus groenlandicus*), and harbour seals (*Phoca vitulina*) were also taken occasionally. Although typically considered an inshore species, harbour porpoises were regularly reported in deep water (>2000 m), in the Newfoundland Basin and Labrador Sea. Atlantic white-sided dolphins were often caught along the edge of the continental shelf and appeared to prefer relatively warm water. Finally, catch records indicate that waters of the Newfoundland Basin and Southern Grand Banks may contain important winter habitat for several small species of cetacean.

Keywords: Atlantic salmon, Atlantic white-sided dolphin, bycatch, distribution, habitat use, harbour porpoise, Northwest Atlantic.

Introduction

Several species of small odontocete (toothed whales) are encountered in Northwest Atlantic waters off Newfoundland and Labrador (Canada; Figure 1), including harbour porpoise (*Phocoena phocoena*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), white-beaked dolphin (*L. albirostris*), common dolphin (*Delphinus delphis*), and long-finned pilot whale (*Globicephala melas*). However, little is known about the abundance or the distribution of most species (Katona *et al.*, 1993; Ledwell, 2005; Lawson and Gosselin, 2009), because dedicated survey effort in the area historically has been limited and often hampered by the prevailing environmental conditions (high winds, waves, seasonal ice cover). In the absence of dedicated survey data, records from other sources, including serendipitous sightings or bycatch records, can be used to deduce cetacean distribution patterns, acknowledging the potential for bias attributable to uneven distribution of sampling effort or uncertainty regarding species identification. Harbour porpoises are typically observed nearshore in summer, but have been recorded farther offshore over the continental shelf (Stenson, 2003). Based on survey and molecular data, four Northwest Atlantic subpopulations are currently recognized in the Gulf of Maine/Bay of Fundy, Gulf of St Lawrence, off Newfoundland and Labrador, and off West Greenland (Gaskin, 1984, 1992a; Donovan and Bjørge, 1995; Wang *et al.*, 1996; Rosel *et al.*, 1999). There is, however, limited information about their fine-scale distribution within these areas; similarly, the extent to which these subpopulations are reproductively isolated is not well understood. Even less is known about the distribution of other odontocetes in the region. Both white-beaked and Atlantic white-sided dolphins are found in shelf waters, with white-beaked dolphins consistently observed in cooler water from Cape Cod to Davis Strait, as well as off western Greenland, and Atlantic white-sided dolphins ranging from the Gulf of Maine to the Labrador Sea (Gaskin, 1992b; Palka *et al.*, 1997; Reeves *et al.*, 1999a, b; Lien *et al.*, 2001). Common dolphins off the northeastern US and in Atlantic Canadian waters are thought to form a single subpopulation within the greater North Atlantic, migrating offshore of Newfoundland and Nova Scotia in summer (Gaskin, 1992c; Gowans and Whitehead, 1995; Waring *et al.*, 2006). Long-finned pilot whales were historically common nearshore off Newfoundland, supporting a drive fishery in some areas until 1972 (Sergeant, 1962; Ledwell, 2005). In recent years, pilot whales have been observed only rarely nearshore off Newfoundland and appear to be restricted to offshore areas (Lawson and Gosselin, 2009). The abundance of shortfin squid (*Illex illecebrosus*), an important prey species, has fluctuated considerably in the past two decades, possibly driving small-scale changes in the distribution of pilot whales (Hendrickson *et al.*, 2005; E. Dawe, DFO–NL, pers. comm.).

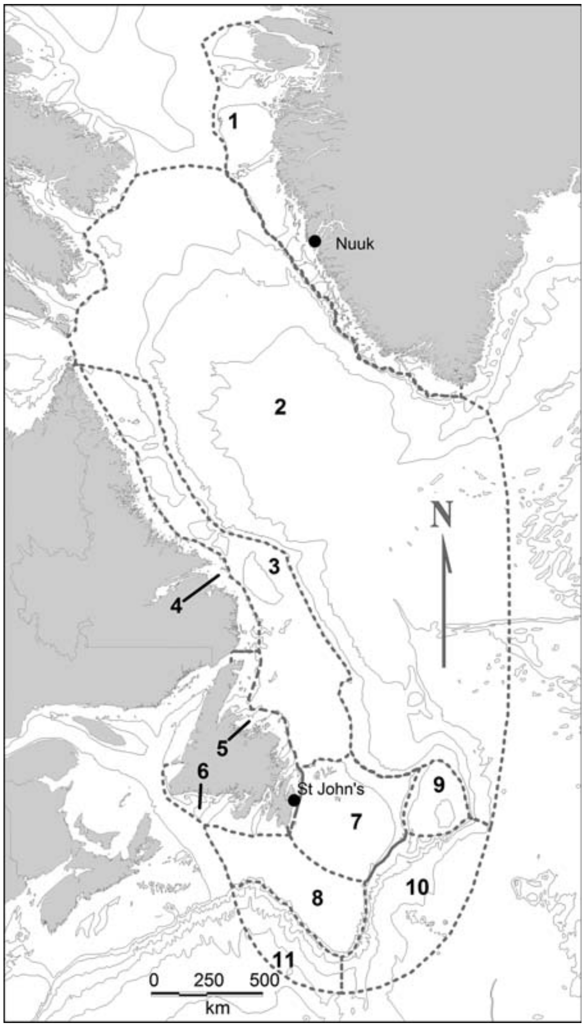

Figure 1. Map of Northwest Atlantic waters indicating the geographic areas used in this study. 1, West Greenland; 2, Labrador Sea; 3, Labrador/Newfoundland Shelf; 4, Labrador nearshore; 5, Newfoundland nearshore (northeast); 6, Newfoundland nearshore (south); 7, Northern Grand Banks; 8, Southern Grand Banks; 9, Flemish Cap; 10, Newfoundland Basin; 11, Southern Slope of Grand Banks. The 200, 1000, 2000, 3000, 4000, 5000, 6000, 7000, and 8000-m isobaths are indicated.

Small odontocetes are often caught accidentally in fishing gears, particularly gillnets (IWC, 1994; Read, 1994; Donovan and Bjørge, 1995; CEC, 2002; Stenson, 2003). One fishery that historically had a considerable impact on small cetaceans in the region is the fishery for Atlantic salmon (*Salmo salar*; Lear and Christensen, 1975; Christensen and Lear, 1977; Teilmann and Dietz, 1998), which used a combination of small-mesh driftnets and set gillnets at, or just below, the surface. The Newfoundland and Labrador commercial salmon net fishery peaked in the 1970s with annual landings of ~3000 t, but was closed in 1992 (in 1997 off Labrador) in response to widespread concerns over declining salmon stocks (O'Connell *et al.*, 2005). The foreign driftnet fishery in Greenland waters, which during the 1960s and 1970s contributed most of the effort in the area, closed in 1976 but was quickly replaced by local fisheries. Quotas in Greenland were reduced dramatically in the early 1990s, and only small-scale artisanal fishing (<20 t) continues now (NASCO, 2010). No large-scale net fishery for Atlantic salmon has ever operated in the Labrador Sea beyond the Canadian 200-mile Exclusive Economic Zone.

To collect biological data on salmon targeted by commercial fisheries, the Canadian federal Department of Fisheries and Oceans, Newfoundland and Labrador (DFO–NL) conducted experimental driftnet fishery surveys for Atlantic salmon in the northwest Atlantic from 1965 to 2001. The objectives of those studies included tagging salmon for studies on migration, stock origin, and distribution, as well as collecting stomach samples (for feeding studies) and environmental data (including sea surface temperature, SST; Lear, 1980; Reddin and Burfitt, 1980; Reddin, 1985).

Many other species, including marine mammals, were recorded as bycatch in official trip logs during the course of the fishery, so the dataset represents the most comprehensive source of information on bycatch of marine mammals in a pelagic fishery in the Northwest Atlantic. Bycatch of marine mammals during driftnet salmon fisheries, particularly harbour porpoises in west Greenland, have been described previously (Lear and Christensen, 1975; Christensen and Lear, 1977; Piatt and Reddin, 1984), but although those studies provided valuable information on bycatch, they were based on datasets that were spatially and temporally limited. In contrast, the DFO–NL dataset covered a wide geographic area (from the Grand Banks and nearshore waters of Newfoundland to the Labrador Sea and coastal Greenland) and contained data from most years between 1965 and 1991, with several additional trips in later years until 2001. These areas have been poorly surveyed historically and little information on marine mammal distribution has been available, particularly offshore, until recently (Lawson and Gosselin, 2009). As salmon nets were deployed at or near the surface, bycatch rates of marine mammals were assumed not to be influenced by interspecific differences in diving capabilities. In addition, salmon driftnets typically were constructed of thin monofilament polymer, which may be difficult to detect by echolocating odontocetes (Au and Jones, 1991; Mooney *et al.*, 2004). For these reasons, marine mammal bycatch records from this dataset may be a better proxy for their distribution and diversity than similar records from bottom-set gillnet fisheries. The fact that nets were fished during different times of the year over a large area allows an analysis of different species' relative abundance in different areas and seasons. Finally, the environmental data collected during these surveys (particularly SST) can be used to infer habitat preferences in some of the more commonly caught species. The objective of the study was to use the experimental salmon driftnet dataset to examine marine mammal bycatch records over a large geographic area from 1965 to 2001, to obtain information on distribution, relative abundance, and habitat use of small marine mammals in the Northwest Atlantic.

Methods

Data were collected from DFO–NL research cruises conducting surface driftnetting operations to capture salmon alive between 1965 and 2001. For comparative purposes, the areas fished were divided into 11 regions (Figure 1) based on depth and prevalent oceanographic conditions: (1) West Greenland, (2) Labrador Sea, (3) Labrador/Newfoundland Shelf, (4) Labrador nearshore, (5) Newfoundland northeast coast, (6) Newfoundland south/southwest coast, (7) Grand Banks of Newfoundland: Northern Grand

Banks, (8) Grand Banks of Newfoundland: Southern Grand Banks, (9) Grand Banks of Newfoundland: Flemish Cap, (10) Newfoundland Basin, and (11) Southern Slope of the Grand Banks.

Cruises were grouped into three seasonal periods, March–June (spring), July–October (summer/autumn), and November–February (winter). Sampling effort was not random across all 11 areas in all seasons, mainly because of the poor weather conditions in northern areas during winter. Net deployment locations were selected randomly during the course of salmon sampling operations by placing a 1 × 1 degree grid over the map in which each square was numbered; a random number table was then consulted to choose the square in which nets were to be deployed. Adjustments were made depending on weather considerations and steaming distance to the next site, as well as other marine traffic (particularly for nearshore sets). As a result, research fishing frequently occurred in areas where there were no viable commercial fisheries, e.g. offshore in the Labrador Sea. Salmon were captured using surface-set driftnets ~46 m long and ~3.1 m deep. Mesh sizes (length of mesh opening) varied from 77 to 165 mm, with 86% of effort involving mesh sizes of 127–152 mm. Three or four different mesh sizes were typically used in a single set. An array of individual nets of alternating mesh size or composition was fished as a unit. Several units were combined into fleets varying in length from 0.30 to 6.48 km long (mean = 2.61 km, s.d. = 1.53 km). Fishing methodology did not differ substantially from prevailing standard practice in the commercial fishery, except that experimental sets used smaller nets (up to ten times shorter than, and only half as deep as, those used in commercial sets) that were deployed and hauled slightly differently (because of the different vessel configurations and to facilitate gear handling during salmon tagging).

For each set location, fishing details (duration, mid-set time, fleet length, mesh size), SST, sea state, light conditions, salmon catch (per mesh size category), and catches of non-salmonid species, including all marine mammals, were recorded. As the research objectives of cruises differed over years, there were minor variations in methodology and types of equipment used during experiments. However, bycatch events were systematically recorded on all surveys throughout the study period.

The duration of fishing varied between 1.2 and 53.3 h, averaging 7.4 h (s.d. = 4.4 h). Although there was greater variability in setting techniques in earlier years, nets were typically set before dawn and hauled back aboard around midday (weather permitting). Most (58.1%) were set between midnight and 06:00, and of those, 63.4% were recovered before midday. Just 10.7% were set after 18:00. For 69 sets (12%), the exact start and end time was not recorded. During fishing operations, nets were patrolled frequently from a small open boat to tag any salmon caught and to release bycatch if possible. Because of this practice, most marine mammals caught were released alive from the driftnets, although exact numbers were not available. The marine mammals were identified by experienced personnel using field guides.

Data from all years were combined and sorted based on geographic area and season. Catch rates of marine mammals in different sets (including both dead animals and those released alive) were compared based on geographic area, season, soak time, SST, and the number of salmon caught in the net. Data were resampled and analysed using two-way comparison testing following the standard bootstrapping procedures (Blank *et al.*, 2001).

Results

Fishing effort and bycatch

In all, 574 sets were carried out during 47 cruises between 1965 and 2001. Effort, expressed as the number of kilometres of nets fished multiplied by the number of hours fished, totalled 12 566.51 km-h (Table 1). In total, 282 sets were made during spring and 279 in summer; an additional 13 sets were made in winter during trips to the Grand Banks (Table 1). The locations of sets made during spring, summer/autumn, and winter are shown separately in Figure 2a–c. There was a distinct seasonal shift in sampling effort, influenced by prevailing weather conditions and the presence of ice, with a concentration of sampling effort in northern regions such as the Labrador Sea and off West Greenland in summer and most sampling effort primarily in southern regions around Newfoundland in spring.

The number of sets per trip varied considerably (1–30 sets) with an average of 12.2 sets (s.d. = 7.3) each trip. The distance between each set varied between trips, but offshore sets were typically at least 50 km apart and nearshore sets typically much closer. Sets were in water depths from <50 m nearshore off Labrador to >5000 m in the Newfoundland Basin. Sampling effort was concentrated in nearshore waters off Newfoundland and West Greenland, and offshore in the Labrador Sea, but no area was sampled annually. Survey effort in most areas was limited, with some areas being surveyed only once or twice during the entire period. Soak times were typically shorter nearshore than offshore, but soak times varied among seasons, years, and regions. Overall, soak times in the experimental fishery did not differ substantially from those practiced in commercial salmon fisheries active in the same area at the same time.

Overall, average SST ranged between 3.1°C (s.d. = 1.5°C; Northern Grand Banks, spring) and 10.2°C (s.d. = 0.4°C; Newfoundland south coast, summer) over the period of study. In total, measured SST varied between 0.5°C (Labrador Sea, spring) and 13.1°C (Newfoundland Basin, winter). This range may have been influenced by interannual variation in sampling effort, as well as the fact that measurements were taken at varying times and locations with regions.

Four species of small cetacean were caught incidentally, including harbour porpoise, Atlantic white-sided dolphin, long-finned pilot whale, and common dolphin (Table 1; Figure 2a–c). Harbour porpoises were the most frequently caught in all areas except the Labrador Sea, where Atlantic white-sided dolphins were more common. Pilot whales were occasionally caught on the Grand Banks, in the Newfoundland Basin and Labrador Sea, and a single common dolphin was caught in the Newfoundland Basin in 1986. In addition, two species of pinniped (two harp seals and a single harbour seal) were captured nearshore off Newfoundland and West Greenland (Table 1; Figure 2a and b). In all, 186 individual bycatch events were recorded for these six species. No attempt was made to identify individual animals, so the possibility of recapturing previously released animals cannot be excluded. There is no evidence that any large whales (e.g. sperm or baleen whales) were ever taken incidentally in this fishery.

Harbour porpoise

In total, 102 harbour porpoises were reported caught between 1965 and 2001. For all years where harbour porpoises were captured, the mean catch of harbour porpoises per unit effort per

Table 1. Total observed numbers, and estimated rates per 100 km-h of effort, of bycatch of marine mammals during experimental salmon tagging fisheries, for all years available combined, per region, and per season.

				Harbour porpoise		Atlantic white-sided dolphin		Long-finned pilot whale		Common dolphin		Harp seal		Harbour seal	
Area	Season	Number of trips	Effort (km-h)	*n*	*n* per 100 km-h	*n*	*n* per 100 km-h	*n*	*n* per 100 km-h	*n*	*n* per 100 km-h	*n*	*n* per 100 km-h	*n*	*n* per 100 km-h
West Greenland	Summer	12	5 265.6	32	1.18 (5.79)	0	0	0	0	0	0	1	0.02 (0.20)	1	0.03 (0.33)
Labrador Sea	Spring	6	858.4	0	0	1	0.16 (0.83)	0	0	0	0	0	0	0	0
	Summer	15	2 526.4	5	0.15 (0.67)	53	1.82 (6.86)	1	0.05 (0.51)	0	0	0	0	0	0
Labrador/ Newfoundland Shelf	Summer	7	255.0	0	0	1	1.21 (4.35)		0	0	0	0	0	0	0
Labrador nearshore	Spring	1	175.4	0	0	0	0	0	0	0	0	0	0	0	0
	Summer	2	203.5	1	0.64 (2.95)	0	0	0	0	0	0	0	0	0	0
Newfoundland Basin	Spring	2	495.3	33	5.39 (7.93)	12	2.70 (4.32)	6	1.34 (2.26)	1	0.34 (1.23)	0	0	0	0
	Winter	1	77.9	8	18.66 (30.11)	0	0	0	0	0	0	0	0	0	0
Southern Slope	Spring	2	71.8	0	0	0	0	0	0	0	0	0	0	0	0
Flemish Cap	Spring	1	75.4	6	8.02 (0.93)	0	0	0	0	0	0	0	0	0	0
Northern Grand Banks	Spring	2	124.3	1	1.44 (3.23)	0	0	0	0	0	0	0	0	0	0
	Winter	2	47.6	0	0	0	0	0	0	0	0	0	0	0	0
Southern Grand Banks	Spring	1	539.3	7	3.42 (9.85)	4	0.47 (1.77)	2	0.24 (0.89)	0	0	0	0	0	0
	Winter	1	34.5	3	7.80 (11.03)	0	0	0	0	0	0	0	0	0	0
Newfoundland northeast coast	Spring	7	927.4	2	0.32 (2.29)	0	0	0	0	0	0	1	0.08 (0.84)	0	0
	Summer	1	18.6	0	0	0	0	0	0	0	0	0	0	0	0
	Winter	1	2.2	0	0	0	0	0	0	0	0	0	0	0	0
Newfoundland south coast	Spring	8	865.5	4	0.57 (3.31)	0	0	0	0	0	0	0	0	0	0
	Summer	1	2.5	0	0	0	0	0	0	0	0	0	0	0	0
Total		47[a]	12 566.5	102		71		9		1		2		1	

Standard deviations (s.d.) are included in parenthesis.
[a]On a number of occasions, several regions were covered during a single trip.

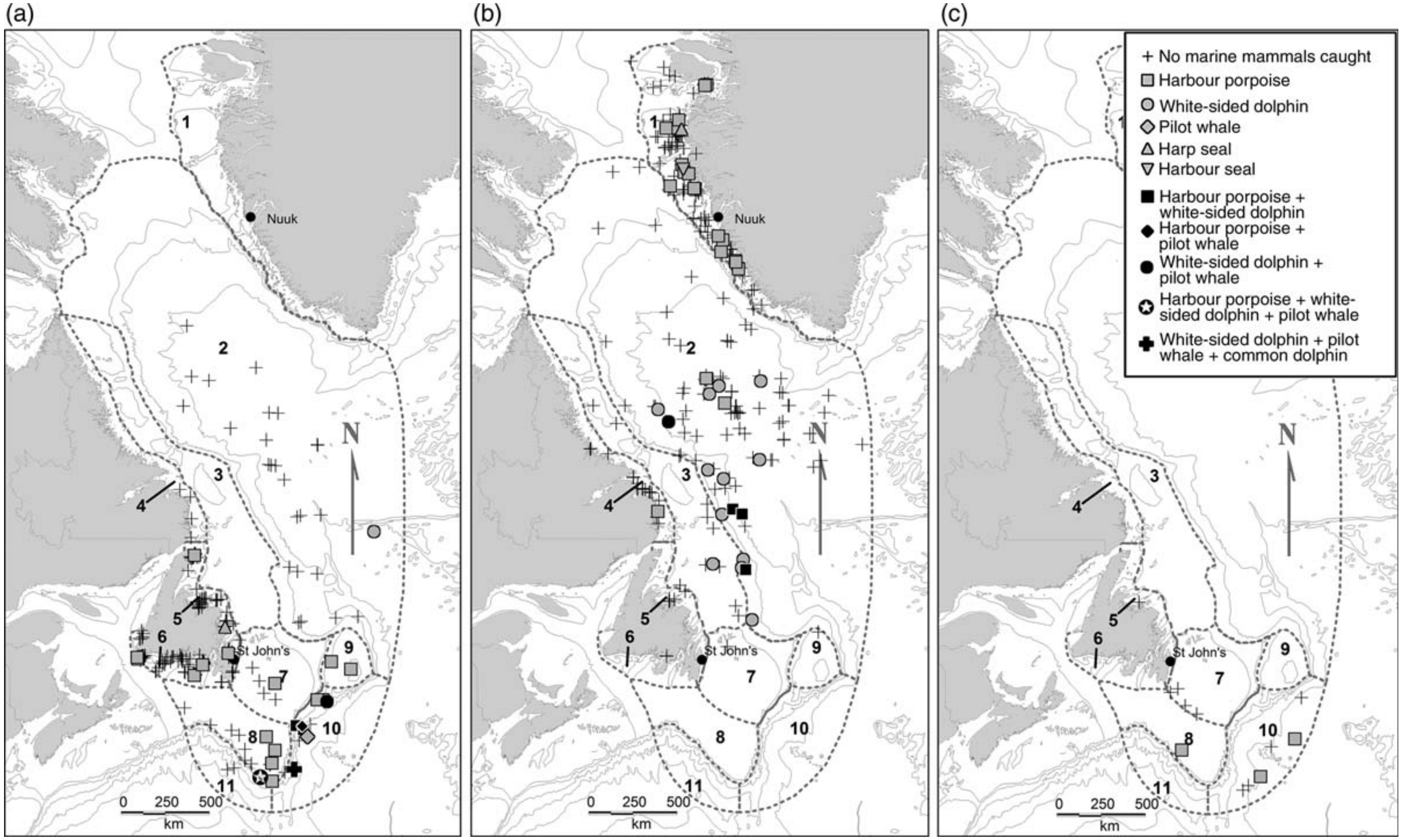

Figure 2. Locations of (a) spring (April–June), (b) summer (July–October), and (c) winter (November–February) sets, and catches of marine mammals during DFO experimental salmon fishery operations. The 200, 1000, 2000, 3000, 4000, 5000, 6000, 7000, and 8000-m isobaths are indicated. Some sets involved multiple animals or >1 species.

region and per season (averaged over all years) varied from 0.15 per 100 km-h in the Labrador Sea during summer to 18.66 per 100 km-h for the Newfoundland Basin in winter (Table 1). However, the likelihood of harbour porpoise catch varied greatly among trips within an area, and no obvious changes in catch rates over time were observed. Overall, more than half the catches ($n = 55$) were in water $\leq$500 m deep, but some were in water as deep as 5000 m.

Most harbour porpoises ($n = 53$) were captured in spring (March–June), a substantial number in deep water (2000–3000 m) of the Newfoundland Basin and along the eastern edge of the Grand Banks (Table 1; Figure 2a). A few were caught nearshore around Newfoundland and on the Grand Banks proper, but none was taken north of the Flemish Cap, although the vast majority of the sampling effort north of the Flemish Cap in spring was in the deep water of the Labrador Sea. It is not clear whether the absence of bycatch in the latter region might also apply to coastal Labrador and West Greenland had more consistent sampling been undertaken there. Between July and October, fishing effort was concentrated in the Labrador Sea and West Greenland areas. High mean bycatch of harbour porpoise (1.18 per 100 km-h) was reported off West Greenland from 1965 to 1982 during summer (Table 1), where a total of 32 porpoises was caught on 9 of the 12 trips. Porpoises were captured all along the coast of West Greenland from 60 to 70°N, except the area around Nuuk (Figure 2b). Other captures were reported from sets made nearshore off Labrador as well as over the adjacent shelf and throughout the Labrador Sea. Most captures involved small numbers (1–3) of animals, although larger numbers (up to 10 animals) were occasionally taken in a single set. In areas sampled during both spring and summer, more porpoises were caught in the southern areas earlier in the year. In winter, porpoises were also caught in deep water of the Newfoundland Basin (4500–5000 m deep), with as many as five animals caught in a single set (Figure 2c).

There was no significant difference between the SST associated with sets that caught porpoises and those that did not, even when assessing catches for each season separately. Soak times of sets that caught porpoises (when combining all areas and periods) were significantly longer in duration than those that did not ($p = 0.004$). The impact of increased soak time on porpoise catches was not apparent when comparing sets within individual regions per season, likely because of the small sample sizes in most runs. The significant result appeared to be driven by a few longer-than-average sets within several regions that also (for reasons unknown) caught large numbers of porpoises. Porpoises were caught less frequently in sets nearshore around Newfoundland, possibly because those sets tended to be shorter in duration, to avoid interference with other nearshore fisheries in the area.

In West Greenland waters during summer, the presence of harbour porpoise appeared positively correlated with high catches of salmon. On average, sets catching at least one porpoise contained 80.4 salmon (s.d. = 113.1), compared with an average catch of 29.4 salmon (s.d. = 37.2 salmon) in sets that did not catch any porpoises ($p = 0.002$). In that area, there was no significant difference in soak duration between sets catching porpoises and sets that did not, demonstrating that increased catches were not correlated with soak time alone. This correlation with salmon catches was not observed in other areas where harbour porpoises were captured.

Atlantic white-sided dolphin

In all, 71 Atlantic white-sided dolphins were reported captured between 1965 and 2001. They were only caught in the Labrador Sea, Labrador Shelf, Southern Grand Banks, and Newfoundland Basin, primarily along the slope of the continental shelf (500–2000 m; Figure 2). Most Atlantic white-sided dolphins were caught singly, although groups of up to 14 animals were captured. In spring, most captures were in the Newfoundland Basin area (2.70 per 100 km-h; Table 1; Figure 2a) whereas captures during summer were reported farther north in the Labrador Sea (1.82 per 100 km-h; Figure 2b). No dolphins were caught during winter. Unfortunately, there was no sampling in the Newfoundland Basin during summer, so it is unclear if the presence of Atlantic white-sided dolphins in the Labrador Sea at this time represents a northward shift in distribution away from the Newfoundland Basin or a seasonal range expansion in response to temporarily improved conditions.

When combining all records, sets that caught Atlantic white-sided dolphins during both spring and summer were made in significantly warmer water than those that did not catch dolphins, namely 6.8°C (s.d. = 1.2°C) vs. 4.6°C (s.d. = 1.9°C) in spring, and 7.0°C (s.d. = 1.1°C) vs. 5.5°C (s.d. = 2.2°C) in summer, respectively ($p < 0.001$). No Atlantic white-sided dolphins were taken in water <5°C, and most were caught in water of ~7°C, considerably warmer than the most commonly reported temperature in the region (~4°C). Within the regions and periods where most Atlantic white-sided dolphins were caught (Newfoundland Basin in spring, Labrador Sea in summer), sets in which dolphins were caught were in marginally warmer water than those that did not, i.e. 6.4°C (s.d. = 0.7°C) vs. 6.3°C (s.d. = 2.1°C) and 7.1°C (s.d. = 1.1°C) vs. 6.9°C (s.d. = 1.8°C), respectively, but these differences were not significant. Neither soak time nor number of salmon caught appeared to correlate significantly with catches of Atlantic white-sided dolphins.

Long-finned pilot whale

In all, nine long-finned pilot whales were reportedly taken incidentally between 1965 and 2001, nearly all during spring along the southwestern edge of the Grand Banks or in the adjacent Newfoundland Basin (Table 1; Figure 2a). All pilot whales were captured singly or in pairs. A single pilot whale was caught in the Labrador Sea during summer (Figure 2b). In these three areas, the mean catch per unit effort per region and per season (averaged over all years) varied from 0.05 to 1.34 per 100 km-h (Table 1). Within these same three areas, there were no significant differences in SST between sets that caught pilot whales and those that did not, but this finding may have been influenced by the small sample size ($n = 6$ sets during two trips). When all records were combined for the entire area, pilot whales were caught significantly more frequently in warmer waters, with an average SST of 7.0°C vs. 5.4°C ($p < 0.001$). Neither soak time nor number of salmon caught appeared to correlate significantly with the likelihood of catching pilot whales.

Other species

A single common dolphin was captured offshore of the Newfoundland Basin in spring 1980 (Table 1; Figure 2a). In nearshore water off West Greenland, individual harp and harbour seals were caught rarely (one each, in summer 1972 and summer 1980, respectively; Figure 2b). Another single harp seal was taken incidentally in spring 1981 off the northeast coast of Newfoundland (Figure 2a). These records were not used for further analysis owing to their scarcity, but they do indicate that other species occasionally became entangled in salmon driftnets.

Assemblages of several species

On 11 occasions, more than one species of marine mammal at a time was captured in the same set. This was primarily in the Newfoundland Basin and typically involved Atlantic white-sided dolphins and at least one other species. On nine occasions, two species were captured, including white-sided dolphins and either harbour porpoises or pilot whales. These sets took place in both spring and summer, in the Newfoundland Basin, Labrador Sea, and adjacent shelf waters. On two occasions (both of which were in spring, near the southern edge of the Grand Banks), three species were captured, including Atlantic white-sided dolphin, pilot whale, and either harbour porpoise or common dolphin. No significant differences were apparent between sets containing multiple species and sets containing a single species, in terms of average soak times, SST, and salmon catches, from comparable areas and periods.

It is worth reiterating that bycatch rates may vary greatly from trip to trip and are heavily dependent on variables such as the abundance of marine mammals, their distribution, and the fishing effort. As an example, on a May 1980 trip to the Newfoundland Basin, in 12 sets over the course of 19 days, 33 harbour porpoises, 12 Atlantic white-sided dolphins, 1 common dolphin, and 6 pilot whales were recorded caught, with several of these events being multispecies captures as described above. Such levels of bycatch during a single trip are exceptional, however, and may indicate the importance to those species of that particular area. The presence of multiple species in an area may increase the likelihood of capturing more than one species in a set, but data are insufficient to allow us to evaluate this possibility.

Discussion

The study has described all incidental bycatch of marine mammals during 47 salmon research cruises in the Northwest Atlantic during the period 1965–2001. Four species of cetacean and two species of pinniped were identified as bycatch in experimental salmon driftnet sets. There were no obvious changes in bycatch rates for any of the four cetacean species identified during the study period; catch per unit effort varied greatly among years, influenced by the unpredictability of large catches. Although the results indicate a potential impact of the salmon driftnet fishery on small cetaceans in the Northwest Atlantic, they could not be used to estimate overall levels of bycatch in the fishery, as done elsewhere (Lear and Christensen, 1975; Christensen and Lear, 1977). This was because of the differences between experimental and commercial salmon fisheries with respect to location, times, and fishing methods. Nevertheless, these data do support the findings from the earlier studies by Lear and Christensen (1975) and Christensen and Lear (1977) by showing that the commercial North Atlantic salmon driftnet fishery likely caught large numbers of marine mammals, particularly harbour porpoises, in the course of its normal operations.

Harbour porpoises in the Northwest Atlantic range from Cape Hatteras in the south to Cape Aston (Baffin Island) and Upernavik (western Greenland) in the north (Gaskin, 1992a; COSEWIC, 2006). The hypothesized population structure first proposed by Gaskin (1984), with partially isolated populations in the Gulf of Maine/Bay of Fundy, the Gulf of St Lawrence, eastern Newfoundland and Labrador, and western Greenland has been broadly confirmed using mitochondrial DNA sequences and contaminant loads (Rosel *et al.*, 1999; Westgate and Tolley, 1999; Tolley *et al.*, 2001). In contrast to divergent mtDNA sequences, only weak differentiation was observed among microsatellite markers from these same populations (Rosel *et al.*, 1999). This lack of nuclear diversity could be caused by gene flow through dispersing males, whereas the observed mtDNA diversity could be maintained by philopatric behaviour of females. These populations may have diverged comparatively recently in response to improved environmental conditions in the Northwest Atlantic following the end of the last glaciation (Tolley *et al.*, 2001). Harbour porpoises are capable of migrating long distances, as shown by the presence of haplotypes thought to be unique to the Gulf of St Lawrence and West Greenland populations among stranded porpoises in wintering areas off the eastern United States (Rosel *et al.*, 1999). Although primarily considered an inshore species, harbour porpoises have been reported offshore in several areas (Rogan and Berrow, 1996; Hammond *et al.*, 2002). The present study confirms that harbour porpoises may be found regularly in deep water (>2000 m) off the continental shelf in the Labrador Sea and Newfoundland Basin (Figure 2), raising also the possibility of reproductive exchange between populations (specifically Newfoundland and Labrador vs. West Greenland). Unfortunately, the gender of the porpoises taken incidentally was not recorded, so it remains unclear whether these areas are used only by dispersing males or by both sexes.

Atlantic white-sided dolphins were taken mostly along the edge of the continental shelf, although the species was recorded in the central Labrador Sea as well as at the edge of the Labrador shelf during summer (Figure 2b). Lack of data precludes a distinction being drawn between a northward shift away from the Newfoundland Basin area or a seasonal extension of distribution, but sightings from a variety of sources demonstrate a continued presence of Atlantic white-sided dolphins along the southeastern edge of the Grand Banks next to the Basin during summer (Lawson and Gosselin, 2009). Although Atlantic white-sided dolphins have been recorded historically as far north as Davis Strait (Gaskin, 1992b), the centre of their distribution has traditionally been considered to lie between New England and the Gulf of St Lawrence (Reeves *et al.*, 1999a). These results indicate that the Newfoundland Basin and Labrador Sea may also constitute seasonally important habitat for Atlantic white-sided dolphins. No records of incidental capture were made from West Greenland despite concerted survey effort, indicating that the species may not be common there.

The absence of white-beaked dolphins in the catch records is somewhat puzzling, because this species is widely distributed in cold water of the Northwest Atlantic (Katona *et al.*, 1993; Ledwell, 2005), and its range is thought to have overlapped widely (both temporally and spatially) with the experimental salmon fishery (Lawson and Gosselin, 2009). White-beaked dolphins are slightly larger and more robust than Atlantic white-sided dolphins (Reeves *et al.*, 1999a, b), so may be better able to extricate themselves from nets. However, the fact that larger pilot whales were taken incidentally in the same fishery and that no dolphins were reported escaping from the nets that were being patrolled argues against this hypothesis. The absence of the species has also been noted in bycatch records from various bottom-set gillnet fisheries in Newfoundland waters (Benjamins *et al.*, 2007). Alternatively, some white-beaked dolphins may have been improperly identified as Atlantic white-sided dolphins, although this appears unlikely given the level of identification expertise among DFO–NL technicians.

Limited catches of long-finned pilot whales along the south-western edge of the Grand Banks and the Newfoundland Basin in spring suggest that this species remains restricted to relatively warm water during that time of year. The capture of a single pilot whale in the Labrador Sea during summer 1988 indicates that pilot whales do frequent the area, at least occasionally. A similar catch in the same area was reported in 2001 in a demersal gillnet targeting Greenland halibut (*Reinhardtius hippoglossoides*; Benjamins *et al.*, 2007). It is unknown whether the low catch rates of pilot whales reflect low abundance, limited spatio-temporal overlap with the experimental salmon fishery, or other factors such as avoidance of fishing gear or a greater ability to escape.

The single catch record of a common dolphin in the Newfoundland Basin during spring is interesting in that it appears at odds with what is currently known of the seasonal distribution of the species. Common dolphins are thought to be seasonal migrants to the Grand Banks and adjacent waters in response to warmer water in summer, and most are thought to winter between Cape Hatteras and Georges Bank (Katona *et al.*, 1993; Gowans and Whitehead, 1995). The presence of a single individual in relatively cool water (6.8°C) in late May indicates that some animals might seasonally range farther north, possibly associated with the North Atlantic Current (Figure 2a). Further observations are required to determine with accuracy the seasonal distribution of common dolphins in waters around the Grand Banks.

The small number of seals reportedly taken incidentally during the course of these surveys ($n = 3$) might at first glance be surprising, given their frequency in the bycatch of other fisheries in Newfoundland and Labrador waters (Piatt and Nettleship, 1987; Sjare *et al.*, 2005). However, such incidental catches typically involve young seals caught in bottom-set gillnets targeting Atlantic cod, lumpfish, and other benthic species in waters close to shore (in locations comparable with the three events reported here; Figure 2a and b). Seals are only rarely reported taken by surface gillnets targeting small pelagic species such as Atlantic herring and may be capable of avoiding such nets at the surface. In addition, seals are often spread widely in the offshore, further reducing the likelihood of seals being caught (Stenson and Sjare, 1997).

The large numbers and diverse assemblage of cetaceans caught near the Southern Grand Banks and the Newfoundland Basin in winter and spring suggest that these areas may be important over-wintering habitat for several species (Figure 2a and c). Those waters have not been systematically surveyed for small cetaceans during winter and spring, and the data presented here offer the best indication so far of their importance to these species at that time of year (see also Gowans and Whitehead, 1995). The same area has been identified before as important summer habitat for humpback whales and other species (Whitehead and Glass, 1985). The confluence between warm waters of the North Atlantic Current and the cold Labrador Current is near the Southern Grand Banks and Newfoundland Basin, resulting in high primary productivity in the area (Drinkwater and Mountain, 1997). Although sample sizes were limited, average spring SSTs in the Newfoundland Basin were 2–3° warmer than adjacent waters on the Grand Banks and in the Labrador Sea. Small cetaceans may therefore favour these waters because of the comparatively clement conditions found there during winter and spring. Limited data available from the Southern Slope of the Grand Banks ($n = 2$ sets) indicate that SSTs comparable with the adjacent Newfoundland Basin are also found there during spring, although no catches of marine mammals were reported. Many small cetaceans have since been recorded during summer along the adjacent shelf edge, captured in bottom-set gillnets targeting monkfish (*Lophius americanus*), skates (Rajidae), and white hake (*Urophycis tenuis*), showing that this area is important to marine mammals during summer (Benjamins *et al.*, 2007). The lack of bycatch records from the Southern Slope of the Grand Banks in the present study may therefore be a result of the very small sample size.

Small cetaceans are not known to fast seasonally so must always remain near a food source, typically fish and invertebrates such as squid (Brodie, 1995). It is unknown what small cetaceans incidentally captured in the Newfoundland Basin were feeding on, because no stomach content data were collected. There is only limited information on prey availability in the area during winter and spring, but offshore stocks of small pelagic species such as capelin (*Mallotus villosus*) and sandlance (*Ammodytes* sp.), as well as a wide variety of epi- and mesopelagic fish (e.g. myctophids) and invertebrates generally found in waters near or beyond the shelf edge, may constitute potential food sources for harbour porpoise, Atlantic white-sided dolphin, and other species (DFO–NL, unpublished data; Read *et al.*, 1996; Craddock *et al.*, 2009). The Grand Banks and slope edge are also important feeding areas for harp and hooded seals during winter and early spring (Stenson and Sjare, 1997; Lacoste and Stenson, 2000; Andersen *et al.*, 2009).

The main lessons suggested by the findings of the present study are threefold. First, the study reiterates the importance of carefully examining historical and/or unconventional data sources (such as the bycatch records reported here) to gather information that is unavailable or difficult to obtain using conventional means. Second, the observations presented point to the potential importance of offshore shelf and pelagic waters in the Northwest Atlantic (especially the shelf edge of the Grand Banks and adjacent Newfoundland Basin) to small cetaceans during particular times of year, potentially in response to locally higher SST. Third, the findings show that harbour porpoises in particular were historically encountered regularly in nets set in the deep waters of the Labrador Sea and Newfoundland Basin, suggesting that pelagic environments within such offshore areas may be of greater significance to this species than heretofore realized.

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