Bycatch of harbour porpoises (*Phocoena phocoena*) in gillnet fisheries of the Estuary and Gulf of St. Lawrence, Canada, 2000-02

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ABSTRACT

The incidental catch of harbour porpoises (*Phocoena phocoena*) in the gillnet fishery of the Estuary and Gulf of St. Lawrence, Canada, was examined using: (1) questionnaires mailed to fishermen inquiring about bycatches in 2000 and 2001 (n=2,277 or 44% of the fishermen with valid licenses); and (2) using data from an at-sea observer programme and sentinel fishery programme in 2001 and 2002. The questionnaire survey had a low response rate (22%) and provided bycatch estimates of 2,215 (95% CI 1,151-3,662) and 2,394 (95% CI 1,440-3,348) porpoises in 2000 and 2001, respectively. The low number of hauls monitored by at-sea observers prevented the estimation of bycatch levels for several zones and the study area as a whole, and provided only imprecise estimates for all other zones. The results from questionnaires indicated a 24-63% reduction in harbour porpoise bycatches since the late 1980s, whereas the at-sea observer programme provided bycatch levels for 2001 and 2002 that were unreliable and underestimated, approaching one quarter of those documented in the late 1980s. Although both indices indicated a decrease in bycatches since the late 1980s, the magnitude of this change remains uncertain given the weaknesses associated with the two approaches. Considering the maximum population rate of increase (R_{max}) for harbour porpoises as 4% and the lower and upper 95% confidence limits (1,440-3,348) of our most reliable estimate of bycatches (i.e. the 2001 questionnaire survey results), the harbour porpoise population in the Gulf of St. Lawrence would need to be at least 36,000-83,700 individuals for current incidental catches to be sustainable. If the rate of increase is less than maximal, e.g. $0.5R_{max}$ or 2%, then 72,000-167,400 harbour porpoises would be needed to attain sustainability. Kingsley and Reeves (1998) estimated that an average 36,000 to 125,000 porpoises occupied the Gulf of St. Lawrence during the summers of 1995 and 1996. Although the trajectory of the population since it was last surveyed in 1996 is uncertain, these findings suggest that bycatch levels might remain a cause for concern for the harbour porpoise population in the Gulf of St. Lawrence. The results from the comparison between the sentinel fishery and the commercial fishery subjected and not subjected to at-sea observations suggest that fine-scale temporal and spatial changes in fishing activities may greatly affect harbour porpoise bycatch levels.

KEYWORDS: GILLNETS; INCIDENTAL CATCHES; HARBOUR PORPOISE; ATLANTIC OCEAN; NORTH AMERICA; CONSERVATION; SUSTAINABILITY; FISHERIE

INTRODUCTION

The management of natural resources and fisheries has traditionally focussed on the effects of directed harvests on the survival and conservation of species or populations. However, the mortality of non-target species through bycatch may represent a significant source of mortality for some species. This is the case for harbour porpoises (*Phocoena phocoena*), a species particularly vulnerable to incidental catches in fishing gear (Perrin *et al.*, 1994). A number of reviews have shown interactions between this species and fisheries throughout most of its range (Gaskin, 1984; Jefferson and Curry, 1994; Bjørge *et al.*, 1994; Stenson, 2003). Although several types of gear such as fish weirs and traps may be involved in these interactions, mortalities are most often associated with fisheries using pelagic or bottom-set gillnets (Smith *et al.*, 1983; Gaskin, 1984; Fontaine *et al.*, 1994a; Jefferson and Curry, 1994; Lien *et al.*, 1994; Stenson, 2003).

Harbour porpoises are widely distributed in the temperate coastal waters of the Northern Hemisphere (Gaskin, 1984). The species occurs at least seasonally in the Estuary and Gulf of St. Lawrence (e.g. Sergeant *et al.*, 1970; Laurin, 1976; Kingsley and Reeves, 1998) and genetics and contaminant profiles suggest that individuals from this region may constitute a distinct population (Gaskin, 1984; Wang *et al.*, 1996; Rosel *et al.*, 1999; Westgate and Tolley, 1999; Tolley *et al.*, 2001; Anderson, 2003). Aerial surveys, which sampled a large portion of the Gulf of St. Lawrence in 1995 and its northern shelf in 1996, provided estimates (uncorrected for visibility biases, such as $g(0)$), of 12,100 (CV=26%) and 21,720 (CV=38%) harbour porpoises in 1995 and 1996, respectively (Kingsley and Reeves, 1998).

Laurin (1976) was the first to suggest that bycatch might represent a non-negligible source of mortality for harbour porpoises in the Estuary and Gulf of St. Lawrence. Two studies conducted during the late 1980s and early 1990s confirmed the existence of substantial harbour porpoise bycatches in the groundfish gillnet fisheries of the Estuary and Gulf of St. Lawrence (Fontaine *et al.*, 1994a; Larrivée, 1996). These mortalities were thought to approach or exceed sustainability levels. Similar concerns were raised for harbour porpoises off Newfoundland and Labrador and for other populations in the northwest Atlantic, including West Greenland and the Bay of Fundy/Gulf of Maine (Gaskin, 1984; 1992; Lien, 1987; Read and Gaskin, 1988; Bravington and Bisack, 1996; Trippel *et al.*, 1996; Bisack, 1997a; Caswell *et al.*, 1998; Teilmann and Dietz, 1998; Department of Fisheries and Oceans, 2001).

During the early 1990s, the collapse of several groundfish stocks in the northwest Atlantic resulted in substantial reductions, and even moratoria, of several fisheries. In the Gulf of St. Lawrence, the Atlantic cod (*Gadus morhua*) fishery, which accounted for most of the harbour porpoise incidental catches in this area in the late 1980s (Fontaine *et al.*, 1994a), was closed in 1993 (southern Gulf) and 1994 (northern Gulf). The fishery in the northern Gulf was reopened at a low level in 1997, but restricted to longlines for 1997 and 1998, and was closed again in 2003. In the southern Gulf of St. Lawrence, the gillnet fishery reopened

in 1997 at reduced levels, but was closed again in 2003. The reduction in groundfish fishery activities should have had beneficial impacts on harbour porpoise populations by reducing incidental catches in fishing gear (Department of Fisheries and Oceans, 2001). These suspected trends were confirmed in the Gulf of Maine where a decrease in bycatch levels was observed following the reduction in fishing effort and implementation of the Take Reduction Plans in 1999 (Waring *et al.*, 2001). A reduction in harbour porpoise bycatch was also observed in the Bay of Fundy component of this population during 1998-2001 (Trippel and Shepherd, 2004). However, bycatches in the nearshore Atlantic cod fishery of Newfoundland were not negligible during 2002, although confidence intervals around the estimates are large (Lawson *et al.*, 2004).

The objectives of this study were to describe the distribution and level of gillnet fishing activity in the Estuary and Gulf of St. Lawrence in 2000-02 and to estimate incidental catches of harbour porpoises in this fishery. An approach similar to the one used in the late 1980s and early 1990s, i.e. questionnaires mailed to gillnet fishermen, was employed to allow comparisons between the two periods (Fontaine *et al.*, 1994a; Larrivée, 1996). Bycatch estimates obtained through questionnaires suffer from numerous problems, as they are based usually on a small number of respondents whose capacity of recollection of bycatch numbers varies depending on the number of incidents, motivation, time elapsed since the end of the fishing season and their trust in the interviewer (Lien *et al.*, 1994). Therefore, harbour porpoise incidental catches were also examined using a more reliable (when properly implemented) technique: independent observers onboard fishing vessels (IWC, 1994; 1997; Donovan and Bjørge, 1995).

MATERIALS AND METHODS

The study area encompassed the Lower St. Lawrence Estuary and the entire Gulf of St. Lawrence, i.e. Northwest Atlantic Fisheries Organisation (NAFO) Divisions 4R, 4S and 4T. These divisions were partitioned into five zones based on the spatial distribution and intensity of gillnet fishing activities: northwestern Gulf; Miscou; southern Gulf; North Shore; and 4R (Lesage *et al.*, 2004; Fig. 1).

Data on incidental catches of harbour porpoises were obtained using two approaches: (1) questionnaires mailed to fishermen after their fishing season; and (2) collection of bycatch numbers directly from fishing vessels, either by the fishermen themselves or by independent observers.

Mail survey

During October-November 2001, questionnaires were mailed to a random sample of 2,277 (or 44%) of the 5,137 owners of gillnet fishery licenses valid in 2000 for groundfish, Atlantic herring (*Clupea harengus harengus*) or mackerel (*Scomber scombrus*) of the Estuary or Gulf of St. Lawrence. Fishermen were asked similar questions to those formulated by Fontaine *et al.* (1994a), i.e. the number of harbour porpoises caught during 2000 and 2001, month and location of capture and type of fishing gear. Fishermen were also asked to report observations of harbour porpoises, incidental catches of other marine mammals, damage to fishing gear and their impressions on the trends of populations of harbour porpoises and pinnipeds. Only the information related to harbour porpoise bycatches is presented here.

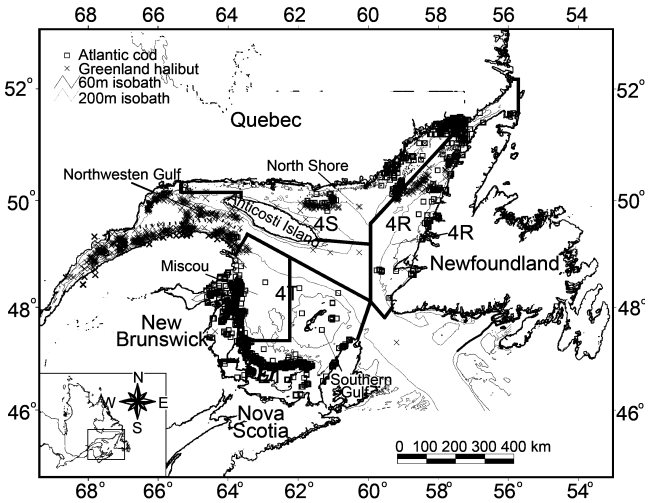

Fig. 1. Distribution of Atlantic cod (squares) and Greenland halibut (crosses) commercial fishing activities using bottom-set gillnets in the Estuary and Gulf of St. Lawrence in 2001 and 2002. Information on fishing location was unavailable for 90-94% of the fishing activities in zone 4R. The thick solid lines delimit the five zones referred to in the document, whereas the dotted line prolongs the limit between NAFO zones 4S and 4T.

Data obtained directly from fishing vessels

An at-sea fisheries observer programme had existed in the Gulf of St. Lawrence since the early 1980s. This programme consists of having an independent observer onboard commercial fishing vessels to collect information on fishing activities, including fishing location, gear type, catches and discards. Observers are not specifically dedicated to the collection of data on marine mammal bycatches. However, in area 4R, datasheet coding for harbour porpoise bycatches have existed since 1989 and marine mammal bycatches have been documented routinely and consistently over the years (D. Kulka, DFO, St. John's, NL, pers. comm.). In areas other than 4R, no such coding existed on the datasheets prior to 2001 and observers may not have collected this information systematically during this period. In 2001 and 2002, coding for each marine mammal species was added to datasheets, and the importance of noting marine mammal bycatches was emphasised during the annual training sessions of observers. When not specified in the remarks section, the number of captured porpoises was estimated from the reported mass, assuming a mean mass per individual of 50-60kg (Read and Tolley, 1997).

The intensity of observation of the fishery by the at-sea observer programme is dictated by harvesting plans and varies with the type of fishery. During 2001 and 2002, coverage for the fixed gear Atlantic cod fishery should have been at least 5% for vessels less than 45 feet in length and at least 10% for larger vessels during both years. Coverage should also have been at least 5% for the fixed gear Greenland halibut (*Reinhardtius hippoglossoides*), winter flounder (*Pleuronectes americanus*), American plaice (*Hippoglosoides platessoides*) and witch flounder (*Glyptocephalus cynoglossus*) fisheries.

A second monitoring programme of the fisheries of the Gulf of St. Lawrence, the sentinel fishery programme, was initiated in 1994. The intent of this programme was not to monitor commercial fishing activities, but to obtain information on population trends of commercially valuable but non-abundant species using predefined scientific fishing protocols and gear types. In this context, fishermen can be asked to deploy their fishing gear in non-traditional fishing

areas during periods of low abundance or low density of the targeted fish species. Data collected through the sentinel fishery programme are very similar to those obtained through the at-sea observer programme and include incidental catches of marine mammals and measurements or sampling of targeted species. In area 4T, every fixed gear sentinel fishing vessel has an observer who handles the data collection and fish sampling when catches are hauled on board. In areas 4R and 4S, information on catches and discards associated with the fixed gear fishery are noted by fishermen themselves since there are no observers dedicated to these vessels. During 2001 and 2002, Atlantic cod was the only species targeted by the fixed gear sentinel fishery programme in the study area.

Total fishing effort and bycatch estimates

An index of the level of activity by the commercial fishing fleet was obtained from data on total landings of all fish species in terms of 'live' kilograms of fish through purchase slips, logbooks and dockside monitoring. This database provided information on target species and type of fishing gear, but was incomplete with respect to fishing location, gear length, soak time, etc. because logbooks are not mandatory for all types of fisheries and, in the case of some of the NAFO Divisions, for smaller vessels. The information presented here on the distribution of the fishery was available from only one of the three possible sources of information in the commercial fishery database (i.e. logbooks) and thus, must be viewed as incomplete.

In the questionnaire survey, harbour porpoise bycatch estimates were calculated using an active fisherman as the unit of effort, i.e. bycatch estimates were expressed as a number of bycaught porpoises per respondent (Fontaine *et al.*, 1994a; Larrivée, 1996). A fisherman was considered active if he had landed fish at least once during the fishing season. Data were partitioned by year. However, the relatively low response rate from the mail survey (see Results) precluded any spatial or seasonal stratification of the data for the calculation of bycatch rates. An estimate of the total number of bycatches for the study area during a given year was obtained by extrapolating the average bycatch rate of respondents to the total number of gillnet fishermen active during that year. Active fishermen in the different NAFO areas were assumed to have had an equal chance of receiving or completing the questionnaire, i.e. the number of answers that were received was considered proportional to the number of active fishermen in each NAFO area. One way of verifying this assumption would have been to resample both respondents and non-respondents shortly after questionnaires were returned. However, this verification could not be done in a timely fashion following the receipt of questionnaires.

Total landings per haul was chosen as the unit of effort for the calculation of bycatch estimates from the at-sea observer programme and sentinel fishery data. A haul was defined as the retrieval of a string of nets. Because there was no direct measure of the number of hauls in the commercial fishing database, this measure of effort (total landings per haul) by the fisheries under the at-sea observer programme was used to back-calculate total hauls (i.e. the effort) by the commercial fishery from fish landings and to estimate bycatch rates by the entire fishing fleet. Given the low coverage by at-sea observers in several zones, mean landings per haul was calculated globally and not per zone for each target species and year. Bycatch estimates were calculated separately for the Greenland halibut and Atlantic cod fisheries, since the Greenland halibut fishery typically occurred in deep waters of the channels in contrast with the Atlantic cod fishery, which mostly operated in shallower waters (Fig. 1). The low levels of activity by at-sea observers precluded any seasonal stratification of the data.

The spatial distribution of bycatches was examined in relation to fish landings in the different NAFO areas using a single classification goodness-of-fit g test (Sokal and Rohlf, 1969). In cases where respondents to the mail survey fished in more than one NAFO area, bycatch numbers were associated with the NAFO area central to the distribution of their fishery.

Standard bootstrap re-sampling techniques were used to calculate the 95% confidence limits of the bycatch estimates.

RESULTS

The bycatch information from at-sea observers and sentinel fisheries indicated that harbour porpoise bycatches were associated exclusively with gillnets and the Atlantic cod and Greenland halibut fisheries; no bycatches were associated with the other fisheries covered by these programmes, i.e. American plaice and winter flounder fisheries. Consequently, other types of gear (e.g. longlines) and other groundfish fisheries are not further dealt with in this paper. The spatial and seasonal distribution of the American plaice and winter flounder fisheries and their associated at-sea observer coverage and bycatch rates are presented in detail in Lesage *et al.* (2004).

Fishing activities in 2001 and 2002

The Atlantic cod fishery occurred mainly in the 4R and Miscou zones, whereas the Greenland halibut fishery was almost exclusively in the northern Gulf of St. Lawrence (i.e. northwestern Gulf and North Shore zones) and along the northwestern coast of Newfoundland (zone 4R) (Table 1; Figs 2-3). Commercial fishing activities for Atlantic cod were at least twice as intense in zone 4R as they were in Miscou during both 2001 and 2002. However, the number of hauls monitored by at-sea observers in 4R was three to four times less than in Miscou, resulting in a stable coverage of about 9% in Miscou compared to less than 1% in 4R. While the intensity of cod fishing was comparable in the North Shore and southern Gulf zones, coverage by at-sea observers was nearly null in the former and 6-35% in the latter. Similarly, coverage of the Greenland halibut fishery by at-sea observers was relatively high (7-17%) in the northwestern Gulf but nearly null in the North Shore and 4R zones, where intense halibut fishing occurred during both years.

The at-sea observer activities followed relatively closely the seasonal distribution of the commercial fishery for both Atlantic cod and Greenland halibut. Most of the commercial fishery and at-sea observer efforts for Atlantic cod occurred early and late in the season (late July and late September) in the southern Gulf, and mainly in July and early August in the more northerly areas of the Gulf (Fig. 2). For the Greenland halibut fishery in the northwestern Gulf, 4R and North Shore zones, at-sea observer and commercial fishery efforts peaked between early July and late September (Fig. 3).

In contrast, the spatial and temporal distributions of the sentinel fishery for Atlantic cod appeared to be independent of the commercial fishery activities. Sentinel fisheries were the most intense in zone North Shore, with a steady 100

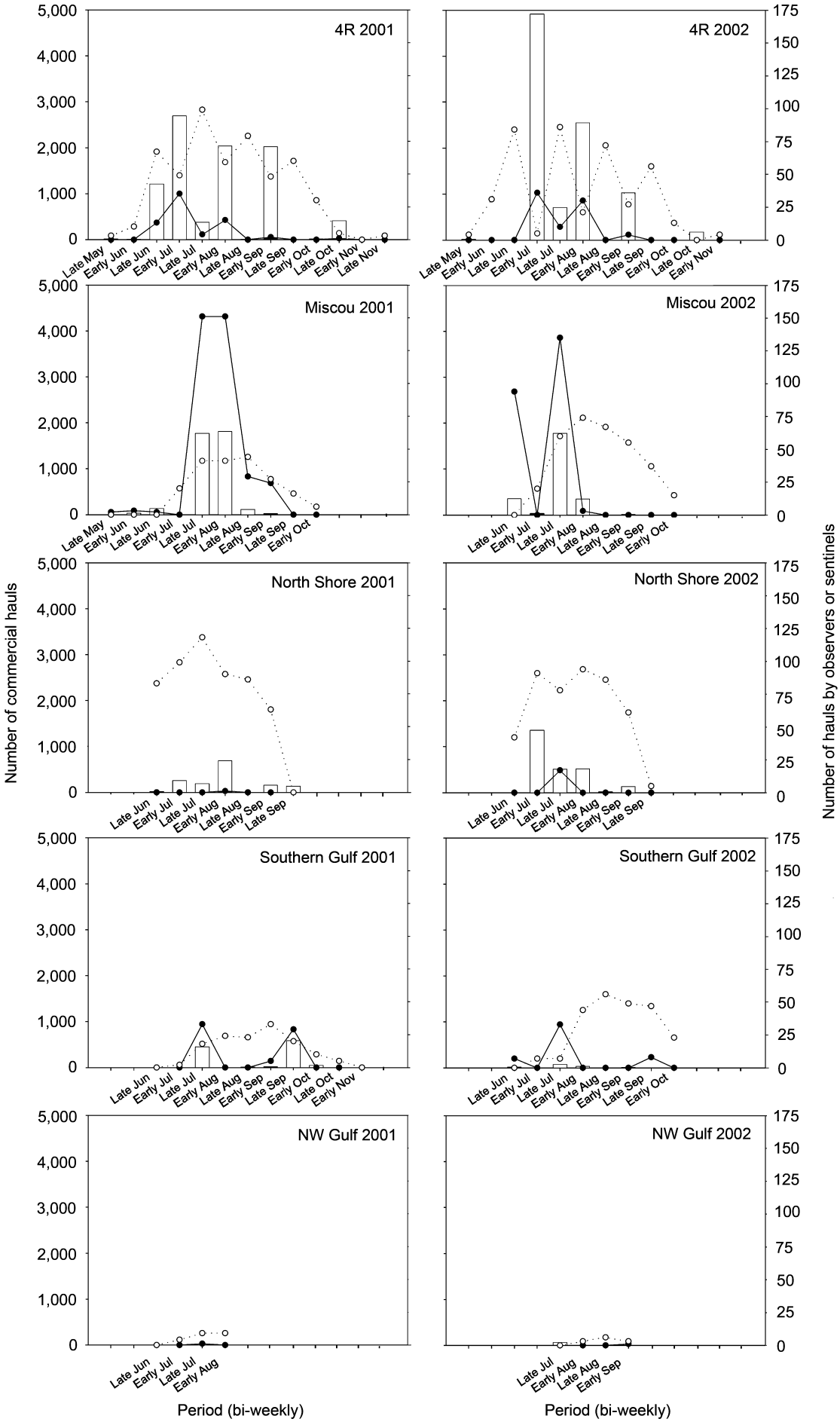

Fig. 2. Seasonal distribution and level of commercial fishing (bars), at-sea observer (solid lines) and sentinel fishery (dotted lines) activities for Atlantic cod in five zones of the Estuary and Gulf of St. Lawrence in 2001 and 2002.

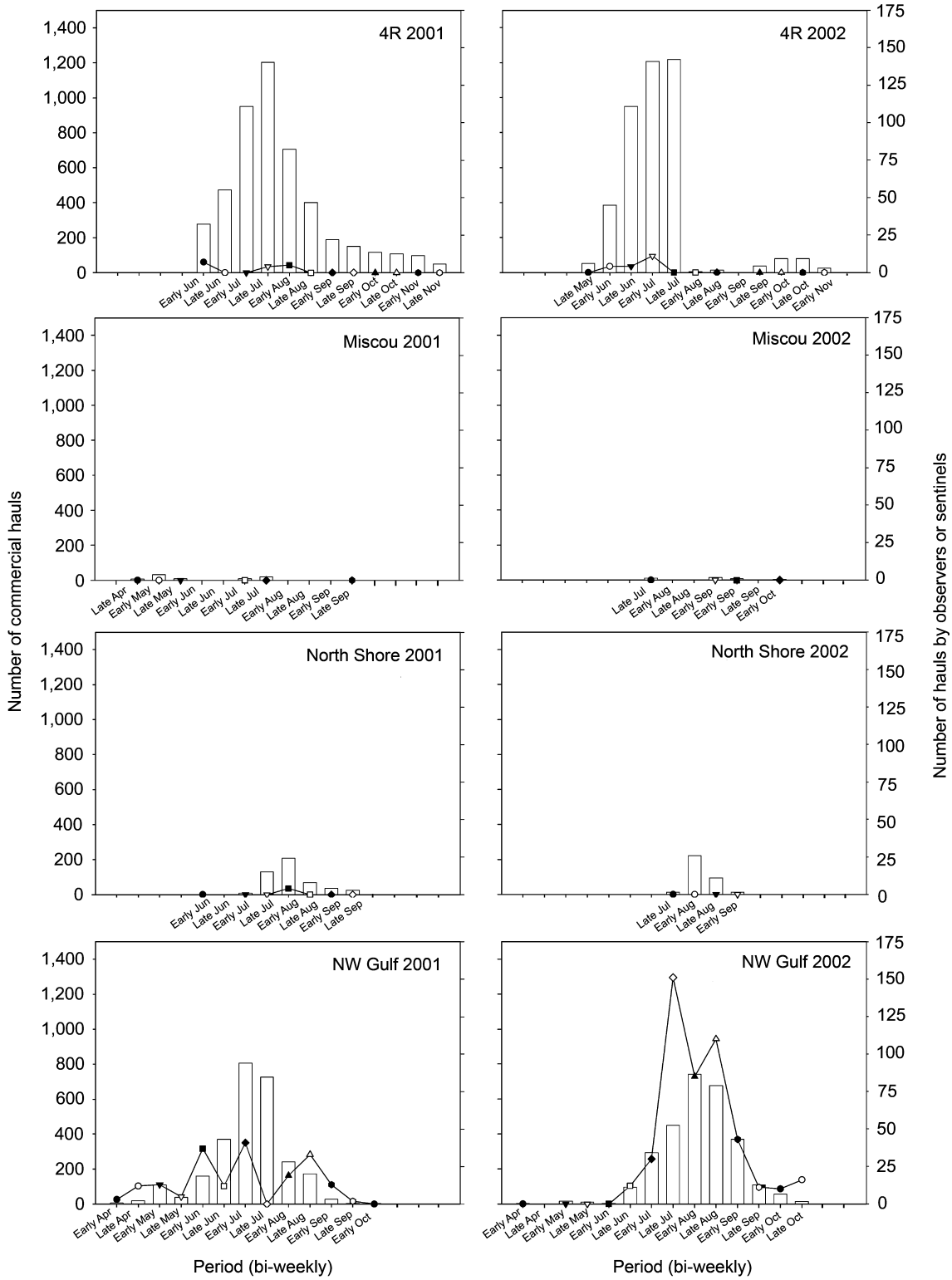

Fig. 3. Seasonal distribution and level of commercial fishing (bars) and at-sea observer (solid lines) activities for Greenland halibut in the four zones of the Estuary and Gulf of St. Lawrence where some fishing occurred during 2001 and 2002.

hauls per year, even though commercial fishing activity was low in this zone compared to Miscou and 4R. Similarly, substantial levels of sentinel fisheries occurred in the southern Gulf in 2002 in spite of little commercial fishing in this zone. Sentinel and commercial fishing activities for cod were low during both years only in the northwestern Gulf. In addition, sentinel fisheries remained highly active over extended periods and included areas and periods with little or no commercial fishing activities (Fig. 2).

Incidental catches of harbour porpoises in 2000-2002

Mail survey

A total of 57% of the 2,277 questionnaires were mailed to fishermen who owned either a groundfish gillnet fishery licence (n=230) or both a groundfish gillnet licence and a herring or mackerel gillnet license (n=1,064). The remaining 983 questionnaires (43%) were mailed to fishermen with only a herring or mackerel gillnet fishery licence. Response rates from groundfish fishermen (57%) and those who

Table 1

Distribution of at-sea observer and sentinel fishery efforts (*n* of hauls) relative to the different types of commercial gillnet fisheries in 2001 and 2002.

	N commercial hauls		*N* observed hauls		Observer coverage (%)		*N* sentinel hauls		*N* harbour porpoises (*N* hauls)			
									Observers		Sentinels	
Zone	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Atlantic cod												
NW Gulf	9	60	1	1	10.9	1.0	22	12	0	0	0	0
North Shore	1,428	2,529	1	17	0.1	1.0	539	457	0	1 (1)	26 (14)	14 (7)
4R	8,814	9,404	70	80	0.8	0.9	512	403	1 (1)	0	11 (6)	13 (7)
Miscou	3,887	2,522	362	232	9.3	9.2	195	329	0	2 (2)	46 (27)	50 (21)
Southern Gulf	1,116	139	67	48	6.0	34.5	135	233	3 (3)	0	3 (2)	0
Greenland halibut												
NW Gulf	2,686	2,835	190	468	7.1	16.5	0	0	0	3 (3)	-	-
North Shore	475	328[a]	4	0	0.8	0	0	0	0	-	-	-
4R	4,716	4,047	16	19	0.3	0.5	0	0	0	0	-	-
Miscou	61[a]	31[a]	0	0	0	0	0	0	-	-	-	-
Southern Gulf	0	0	-	-	-	-	-	-	-	-	-	-

[a] Estimation based on species' annual mean landing per haul.

possessed only a herring or mackerel gillnet licence (43%) were proportional to the number of questionnaires assigned to each group. Of the 5,137 owners of valid licences, 1,744 (34%) were active in 2000 (Table 2). Assuming that the 2,277 questionnaires were sent randomly to active and inactive fishermen, an expected 774 questionnaires (i.e. 34%) were sent to active fishermen. Based on this assumption, response rates from active fishermen (n=258) and active fishermen who provided useful information on bycatch levels (n=173) were 33% and 22%, respectively (i.e. 258 and 173 of 774 active fishermen).

In total, 188 and 296 harbour porpoise bycatches were reported by 37 (24%) and 47 (27%) fishermen in 2000 and 2001, respectively (Table 2). Bycatches were the highest in the northeastern Gulf (i.e. NAFO areas 4Sv, 4Sw, 4Ra and 4Rb), in the southern Gulf near Prince Edward Island and western Cape Breton (i.e. NAFO areas 4Tg, 4Th and 4Tj), at the entrance of Baie des Chaleurs (i.e. NAFO area 4Tn) and in the northwest extreme of the Gulf of St. Lawrence (i.e. NAFO area 4Sz) (Fig. 4). The overall distribution of bycatches among the 19 NAFO areas where bycatch data were available from questionnaires differed significantly (g=278.3 and 337.7 in 2000 and 2001, respectively; df=18; p<0.0001) from the distribution expected if proportional to fish landings. Bycatches were generally higher than expected from landings in 2000 and 2001 in NAFO areas 4Sv and 4Sw (31 and 6% of total bycatches vs 5 and 9% of total landings), 4Tg, 4Th and 4Tj (9 and 22% of bycatches vs 7 and 5% of landings), 4Tn (31 and 28% for bycatches vs 19 and 12% of landings) and 4Sz (4-8% of bycatches vs 0.1 and 0.1% of landings). However, this was not the case in NAFO areas 4Ra and 4Rb, where bycatch numbers were either proportional or lower than expected from landings (19 and 32% of bycatches vs 22 and 49% of landings in 2000 and 2001, respectively). The seasonal distribution of bycatches also did not follow the seasonal distribution of fishing effort (g=121.8 and 33.6 in 2000 and 2001, respectively; df=6; p<0.0001). Bycatches were the highest in July and August during both years, and were higher than expected from fish landings during these months in 2000 (38 and 38% of bycatches vs 20 and 24% of landings) but not in 2001 (35 and 26% of bycatches vs 36 and 28% of landings). However, bycatches remained high during September in 2001 when fishing activity declined and thus, were

Table 2

Estimates of harbour porpoise bycatches during 2000 and 2001 calculated from a mail survey of fishermen with valid groundfish, Atlantic herring, or mackerel gillnet fishery licenses for the Estuary or Gulf of St. Lawrence in 2000. Confidence intervals (CI) were estimated using standard bootstrap techniques.

		Estuary and Gulf of St. Lawrence		Area similar to Fontaine *et al.* (1994a)	
	N (in %)	2000	2001	2000	2001
Fishermen with valid licences in 2000	5,137				
Questionnaires sent to fishermen with valid licenses in 2000	2,277 (44%)				
Questionnaires returned	294 (13%)				
Questionnaires returned by inactive fishermen	36				
Questionnaires returned by active fishermen unwilling to participate	35				
Active fishermen willing to participate	223 (10%)				
Questionnaires with information on harbour porpoise bycatches		152	173	78	89
Fishermen who caught harbour porpoises (in %)		37 (24.3%)	47 (27.2%)	19 (24.3%)	21 (23.6%)
Total number of harbour porpoise bycatches[a]		188	296	133	132
Mean number of bycaught harbour porpoises per fisherman (CV); (95% CI)[b]		1.24 (352%)[b] [0.66–2.10]	1.71 (267%)[b] [1.02–2.38]	1.72 (348%) [0.39–3.05]	1.49 (276%) [0.63-2.35]
Active gillnet fishermen in the fishing fleet		1,744	1,408	781	472
Extrapolation of the number of bycatches to the fishing fleet (95% CI)[b]		2,215 (1,151–3,662)	2,394 (1,440–3,348)	1,343 (307-2,379)	703 (300-1,107)

[a] Assuming a bycatch of one harbour porpoise for fishermen who indicated 'some bycatches'; [b] between-year differences were not significant (t-tests, p>0.05).

significantly higher than expected from fish landings during this month (19% of bycatches vs 12% of landings; Fig. 5). Atlantic cod, herring and mackerel were the species most often associated with porpoise bycatches during both years (Table 3).

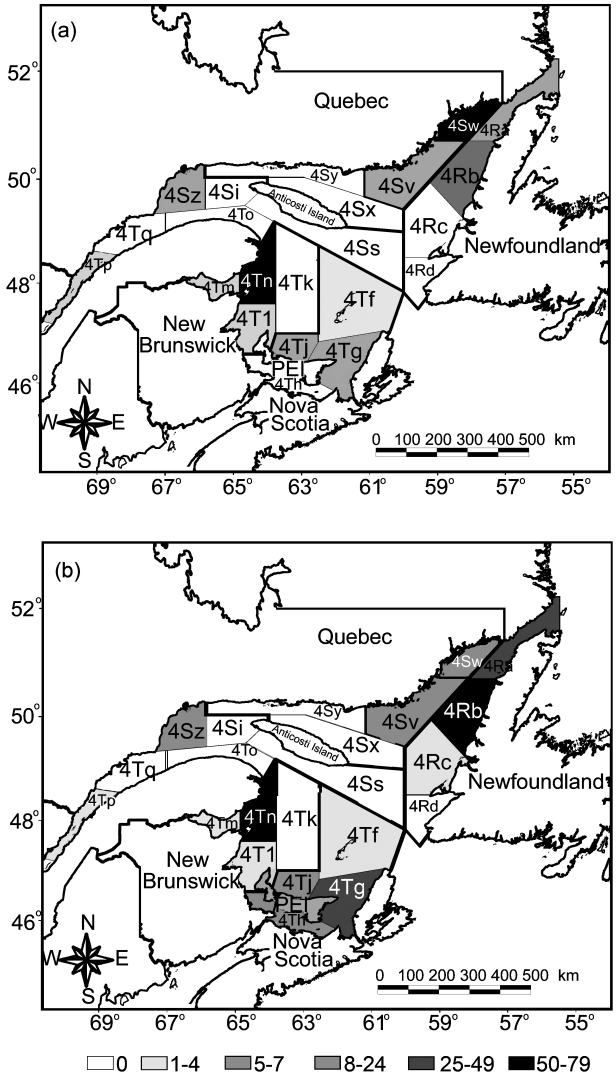

Fig. 4. Distribution of harbour porpoises bycaught in the gillnet fishery in (a) 2000 (n=188 porpoises) and (b) 2001 (n=296), as indicated by a mail survey of gillnet fishermen active during the 2000 fishing season. Ten and 15 porpoises were caught in undetermined locations in 2000 and 2001, respectively. The solid thick lines delimit the five zones referred to in the document (see Fig. 1).

These mortalities resulted in mean bycatch rates of 1.24 (SD=4.4) and 1.71 (SD=4.6) porpoises per reporting fisherman in 2000 and 2001, respectively. Mean catch rates did not differ significantly between years (t=-0.70, p>0.05). Extrapolation of these rates to the entire active fishing fleet using bottom-set gillnets resulted in an estimated total bycatch of 2,215 (95% CI 1,151-3,662) and 2,394 (95% CI 1,440-3,348) porpoises for the Estuary and Gulf of St. Lawrence in 2000 and 2001, respectively. The use of a survey area similar to Fontaine *et al.* (1994a), i.e. the Miscou, North Shore and northwestern Gulf zones, including the area of the Îles-de-la-Madeleine, provided bycatch estimates of 1,343 (95% CI 307-2,379) and 703 (95% CI 300-1,107) porpoises in 2000 and 2001, respectively.

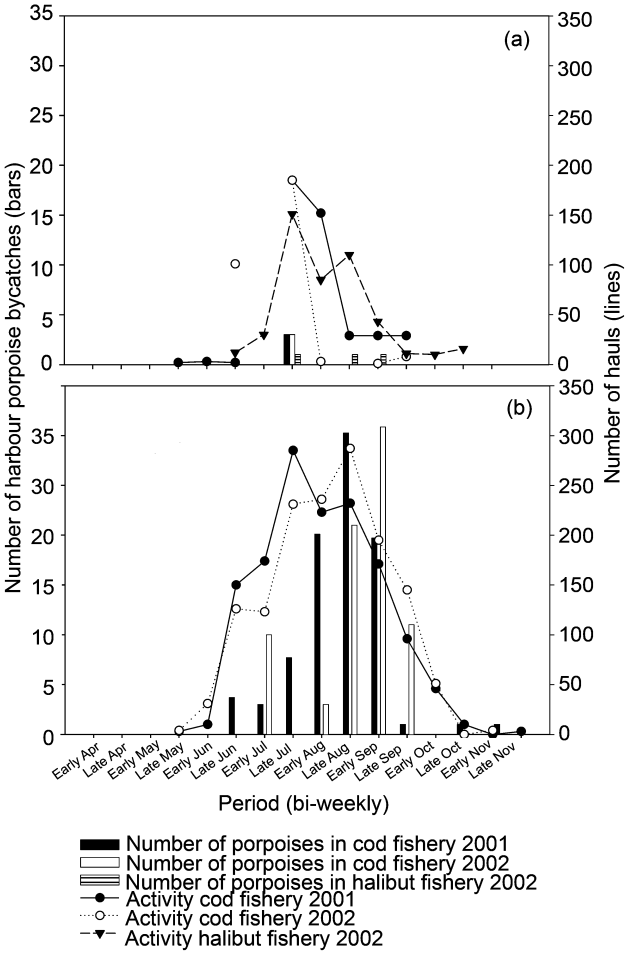

Fig. 5. Monthly distribution of activities (lines) by (a) at-sea observers and (b) sentinel fisheries and incidental mortalities of porpoises reported by these two groups (bars) in 2000 and 2001.

Table 3

Species associated with incidental catches of harbour porpoises during 2000 and 2001 as indicated by a questionnaire survey of fishermen with valid groundfish, herring, or mackerel gillnet licenses for the Estuary or Gulf of St. Lawrence in 2000.

	2000		2001	
Species associated with harbour porpoise bycatches	*N* of respondents	%	*N* of respondents	%
Atlantic cod	14	41	18	40
Atlantic herring	12	35	18	40
Atlantic mackerel	15	44	17	38
Capelin	5	15	9	20
Flounder	3	9	3	7
Greenland halibut	1	3	1	2
Hake	1	3	1	2
Lumpfish	3	9	3	7
Undetermined	7	21	8	13

At-sea observer and sentinel fishery programmes

Ten harbour porpoise bycatches were reported by at-sea observers in 2001 (n=4) and 2002 (n=6) (Table 1). The Atlantic cod and Greenland halibut bottom-set gillnet fisheries were responsible for seven and three of these catches, respectively. At least six of the seven porpoises caught as part of the Atlantic cod fishery were taken in late July, when most of the at-sea observer activities took place; the date of bycatch was unavailable for an animal caught in zone 4R. The three porpoise bycatches associated with the Greenland halibut fishery occurred in 2002 in the

northwestern Gulf and were spread out in time between late July and early September (Fig. 5a). Porpoise bycatches associated with the Atlantic cod fishery occurred in waters shallower than 60m, whereas at least two of the three captures associated with the Greenland halibut fishery occurred at deeper depths. The low number of hauls monitored by at-sea observers prevented the calculation of bycatch estimates for several zones and the study area as a whole, and provided only imprecise estimates (i.e. large CVs) for all other zones (Table 4). Using the upper confidence limits of mortality estimates, and assuming that bycatches were proportional to fishing effort, total bycatch of harbour porpoises, as estimated from the available at-sea observer data, was probably of the order of 1,000 individuals or fewer in 2001 and 2002.

The sentinel fishery activities resulted in 86 and 77 harbour porpoise bycatches in 2001 and 2002, respectively (Tables 1 and 4). Bycatches in this fishery peaked in late August in 2001 and in early September in 2002, even though commercial fishing activities (g=195.0 and 461.5 in 2001 and 2002, respectively; df=11; p<0.0001) and sentinel fishery activities (g=55.6 and 90.2 in 2001 and 2002, respectively; df=12 and 11; p<0.0001) peaked earlier in the season, i.e. in late July to late August (Fig. 5b). Between 53 and 65% of these harbour porpoise bycatches occurred in the Miscou zone; most of the other mortalities occurred in the 4R and North Shore zones (Table 4).

It is noteworthy that the highest bycatch rates were associated with the sentinel fishery, whose activity occurred over extended periods compared to commercial or at-sea observer fisheries and included areas where target species might have been less abundant. The larger number of bycatches observed in the sentinel fishery (n=31 for 14 hauls in 2001, n=48 for 19 hauls in 2002) compared to the at-sea observer programme (n=0 in 313 and 212 hauls in 2001 and 2002, respectively) at the Miscou Bank (NAFO area 4Tn) was puzzling. The vast majority (26 of 31 and 46 of 48) of the mortalities inflicted by the sentinel fishery occurred in late August and September, when commercial cod fishery activities had decreased (Figs 2 and 5b). Commercial fishing was nearly null and coverage by at-sea observers was non-existent during this period in 2002, which might partly explain why no harbour porpoises were reported that year. During the same period in 2001, 37 hauls were subjected to at-sea observations, but still, none of these hauls were associated with bycatches. A comparison of different parameters related to operations, including fishing depth, number of gear, soak time and fishing location, for periods when the different types of activity occurred at the same period (August and early September) revealed significant differences in fishing characteristics between commercial fisheries, commercial fisheries with at-sea observers on board and sentinel fisheries. Specifically, sentinel fisheries soaked nets of similar length (455m) but with smaller mesh, at deeper depths, for longer periods and for a lower quantity of landed fish than did the commercial fisheries with an observer on board (Table 5). Plotting cod fishing locations in the Miscou zone (NAFO 4Tn) indicated that, at least for August and early September 2001, there was little overlap in fishing location between the two fisheries. There was also little overlap between commercial fisheries with observers on board and commercial fisheries not subjected to at-sea observations (Fig. 6a). Commercial and sentinel fisheries generally followed the 60m isobath, whereas fishing activities with at-sea observers on board occurred in shallower waters, inside the Miscou Bank. In 2002, periods of activity by at-sea observer and sentinel fisheries in area 4Tn did not overlap in time but did overlap spatially (Fig. 6b).

DISCUSSION

The at-sea observer programme and the questionnaire survey provided somewhat inconsistent indices of harbour porpoise bycatch levels in the gillnet fisheries of the Estuary

Table 4

Estimates of incidental catches of harbour porpoises in the bottom-set gillnet fishery in the Estuary and Gulf of St Lawrence using information obtained from the at-sea observers and sentinel fishery programs. The 95% confidence intervals (CI) were estimated using standard bootstrap re-sampling techniques.

			At-sea observers				Sentinel fishery	
Targeted species	Zones	N of commercial hauls	N of bycatches per haul (n hauls)	Estimated mortalities	CV (%)	95% CI	N of bycatch per haul (N of hauls)	Total n of bycatches
2001								
Atlantic cod	NW Gulf	9	-[a]	-[a]	-[a]	-[a]	0 (22)	0
	North Shore	1,428	-[a]	-[a]	-[a]	-[a]	0.048 (539)	26
	4R	8,814	0.0143 (70)	126	99	0–378	0.021 (512)	11
	Miscou	3,887	0 (362)	0			0.236 (195)	46
	Southern Gulf	1,116	0.04478 (67)	50	53	0–100	0.222 (135)	3
Greenland halibut	NW Gulf	2,686	0 (190)	0	-	-		
	North Shore	475	-[a]	-[a]	-[a]	-[a]		
	4R	4,716	0 (16)	0	-	-		
	Miscou	61	-[a]	-[a]	-[a]	-[a]		
2002								
Atlantic cod	NW Gulf	60	-[a]	-[a]	-[a]	-[a]	0 (12)	0
	North Shore	2,529	0.05882 (17)	149	98	0–446	0.031 (457)	14
	4R	9,404	0 (80)	0	-	-	0.032 (403)	13
	Miscou	2,522	0.0086 (232)	22	74	0–54	0.152 (329)	50
	Southern Gulf	139	0 (48)	0	-	-	0 (233)	0
Greenland halibut	NW Gulf	2,835	0.0064 (468)	18	57	0–42		
	North Shore	328	-[a]	-[a]	-[a]	-[a]		
	4R	4,047	0 (19)	0	-	-		
	Miscou	31	-[a]	-[a]	-[a]	-[a]		

[a]The at-sea observer coverage was too low to estimate harbour porpoise bycatch rates.

Table 5

Comparisons of median values and the 10th and 90th percentiles (P10–P90) of different parameters of Atlantic cod fishing operations between sentinel fisheries (sentinels) and commercial fisheries conducted under the at-sea observer program (observers) in area 4Tn during August and early September 2001.

	Sentinels (N = 51)	Observers (N = 188)		
Parameter	Median (P10-P90)	Median (P10-P90)	$F_{\text{ANOVA on ranks}}$	$P > F$
Depth (m)	44 (35–96)	40 (34–56)	14.6	0.0002
Soak time (h)	19.7 (17.8–24)	7.3 (2.5–18)	178.7	0.0001
Mesh (mm)	145 (140–146)	145 (140–152)	10.5	0.001
Landings (kg)	11 (0–377)	134 (30–409)	4.3	0.040

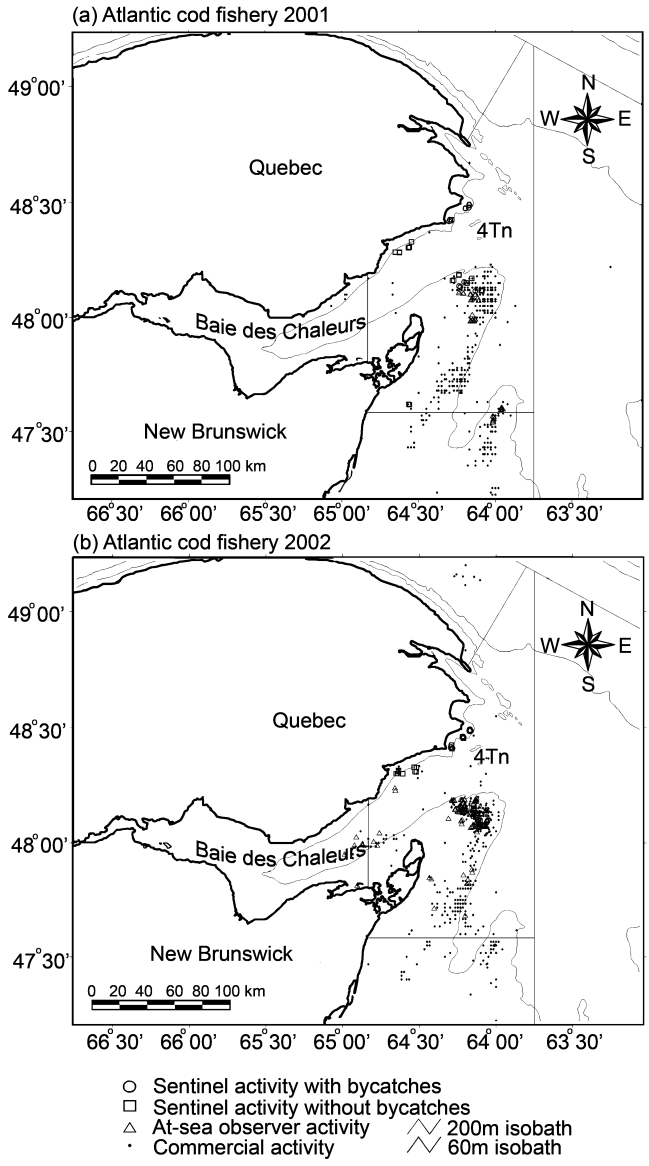

Fig. 6. Spatial distribution of commercial cod fishery activities with and without at-sea observers on board, and of sentinel fisheries that did or did not report harbour porpoise bycatches in NAFO Area 4Tn. Fishing activities in 2001 all took place in August and early September. In 2002, at-sea observer activities occurred between late July and early August and did not overlap temporally with activities by sentinel fisheries, which occurred in late August and September.

and Gulf of St. Lawrence. Estimates obtained using at-sea observer data suggested that 1,000 harbour porpoises or fewer were caught by this fishery during 2001 or 2002, whereas the mail survey estimated a total bycatch of twice as many (2,215 and 2,394) harbour porpoises for 2000 and 2001, respectively. There are some weaknesses associated with the two approaches used in this study to estimate bycatch levels. In contrast to the study by Fontaine *et al.* (1994a), which surveyed all (100%) active fishermen, our study questioned 44% of the fishermen with licences and an estimated 34% of active fishermen. Return rates of questionnaires in the study by Fontaine *et al.* (1994a) were 33% and 18% for 1989 and 1990, respectively. In this study, the return rate from fishermen who provided useful information on bycatch was 22%. Response rates of this magnitude were considered low and their reliability in providing accurate bycatch estimates has been questioned (e.g. Palka, 1994). The quality of the information obtained from questionnaire surveys also depends on diverse biases associated with the willingness of fishermen to transmit information that might impede their future fishing activities (e.g. bias of non-respondents, accuracy of the information provided; Usher and Wenzel, 1987). Mail surveys or interviews also suffer from the capacity of fishermen to recall events that took place weeks or months earlier (Lien *et al.*, 1994). Questionnaires in this study were distributed shortly after the end of the fishing season, which helped reduce the latter bias. While fishermen were asked to provide information on harbour porpoises caught incidentally over the past two seasons, bycatch estimates from the fishing season just preceding the distribution of questionnaires (2001) were considered the most reliable.

There are some indications that bycatch rates obtained through the at-sea observer programme might represent underestimates. The zones identified as being associated with high bycatch levels differed between the mail survey and the fishery-monitoring programme. Fontaine *et al.* (1994a) and Larrivée (1996) had both identified the Gaspé Peninsula (NAFO areas 4Tn and 4To) and the Lower North Shore (areas 4Sv and 4Sw) as being important areas of harbour porpoise bycatch. The sentinel fishery programme and the questionnaires, but not the at-sea observer data, confirmed the importance of these areas for incidental catches of harbour porpoises (Fig 4; Table 1). The absence or low coverage of the Atlantic cod fishery by at-sea observers in the North Shore zone, and to a lesser extent in area 4To, may in part explain the absence of reported bycatches in these sectors.

The use of an independent observer, ideally dedicated to marine mammal research (so-called 'on-watch'), is recognised as being the most desirable approach for obtaining information on marine mammal bycatches (Perrin *et al.*, 1994; Trippel *et al.*, 1996; Bisack, 1997a; Department of Fisheries and Oceans, 2001). However, the amount and distribution of observer coverage must be adjusted so to ensure the detection of a reasonably high number of events and thereby achieve an acceptable coefficient of variation (Bisack, 1997b). As stated by Wade (1999), '... a five percent observer coverage may be sufficient for a very large

fishery, but may be grossly inadequate for a smaller fishery'. In this study, the number of hauls monitored by observers was low throughout the Estuary and Gulf of St. Lawrence and for all groundfish fisheries with the exception of the Greenland halibut fishery in the northwestern Gulf and the Atlantic cod fishery in the Miscou zone (Table 1). In addition, the observers on sentinel fishery or at-sea observer vessels were not entirely dedicated to marine mammal watch, thereby causing an underestimation of incidental mortalities of harbour porpoises in these fisheries. Studies that have compared incidental catches reported by at-sea observers while they were 'on-watch' and 'off-watch' for marine mammals, i.e. while they were or were not actively watching for harbour porpoises in nets being hauled, indicated that a non-negligible (about 18-37%) proportion of bycaught harbour porpoises fall out of the net before being brought on deck (Palka, 1994; Bravington and Bisack, 1996).

The Miscou zone (NAFO area 4Tn) was identified as one of the most problematic areas for harbour porpoise bycatches in the Gulf of St. Lawrence by both Fontaine *et al.* (1994a) and Larrivée (1996). This one sector contributed 13% and 18% of all the bycatches reported by fishermen through questionnaires in 2000 and 2001, respectively, and 62-65% of those reported by sentinel fisheries in 2001 and 2002. However, no bycatches were detected by at-sea observers in this area in 2001 and 2002 in spite of the high number of hauls that were monitored (Table 1). Inconsistencies in data collection between observers are unlikely to be the reason for this discrepancy since the same individuals served as observers onboard sentinel and at-sea observer fishery vessels (M. Jean, Biorex Inc., Caraquet, N.B., pers. comm.). An experimental study conducted by Larrivée (1996) between May and August 1992 in this area (4Tn) indicated a mean bycatch estimate of 3.85 harbour porpoises per landed metric ton of fish. Applying this estimate to the landings reported in this area in 2001 (705t) and 2002 (496t) would have yielded bycatch estimates of 2,714 and 1,910 harbour porpoises, respectively, for area 4Tn alone. The bycatch rate obtained by Larrivée (1996) is probably unrealistic for the 2001 and 2002 situation in this area given the profound changes observed in fishing practices, fishing season and number of operating vessels. However, the results from this simple calculation suggest that a meticulous examination of the data available for this area is warranted.

The comparison of fishing location and timing between sentinel fisheries and commercial fisheries subjected and not subjected to at-sea observation indicated that fine-scale differences in the temporal and spatial distribution of fisheries may greatly influence rates of harbour porpoise bycatch. Fisheries that occurred later in the season (late August and September) and closer to the 60m isobath appeared more prone to causing incidental mortality of harbour porpoises (Figs 5 and 6). Larrivée (1996) obtained similar results in a controlled fishing experiment between the 36m and 55m isobath of the Miscou Bank (area 4Tn) during the period 19 August to 29 September 1994. She observed a decline in cod landings with date and soaking depth, and a parallel increase in harbour porpoise bycatches. Consequently, a larger effort by at-sea observers, closer to the 60m isobath where most of the commercial fisheries activity occurred, might have revealed higher bycatch estimates in area 4Tn. The difference that was observed in 2001 in the spatial distribution between commercial fisheries subjected and not subjected to observer monitoring suggests that fishermen might distribute their fishing effort differently in the presence and absence of at-sea observers. This pattern was not observed in 2002. The absence of information on soak time, depth and other descriptors of the commercial fishery not subjected to at-sea observations precluded further analyses of these patterns that were observed among the different fisheries.

Significant differences in the characteristics of hauls were also observed between the sentinel and at-sea observer fisheries (Table 5). One striking difference was the short soak time (median=7.3h; range 2.5-18h) of the commercial fishery subjected to at-sea observation compared to sentinel fisheries (median=19.7h; range 17.8-24h). These results suggest a deployment and retrieval of nets in the same day by the fisheries subjected to at-sea observations, compared to an overnight deployment by the sentinel fisheries. The effect of soak time on bycatch levels is unclear, with some studies indicating an increase in the number of captures per haul with the amount of time nets are left in the water (Vinther, 1999) and other studies showing a reversed trend or unclear patterns (Palka, 1994; Larrivée, 1996; Department of Fisheries and Oceans, 2001; Hood, 2001). A positive correlation between soak time and harbour porpoise bycatch, if it was to occur, might represent a plausible explanation for the higher bycatch rates associated with the sentinel fisheries.

The increase in harbour porpoise bycatches during late summer could be linked to an influx of harbour porpoises inshore in response to an increase in the abundance of Atlantic herring in coastal waters of the Baie des Chaleurs (LeBlanc *et al.*, 2002a; b). This species, which spawns in the spring and autumn, represented an important prey of harbour porpoises in the Miscou zone both in the late 1980s and in 2001-02 (Fontaine *et al.*, 1994b; Guimont, 2003). This species is also regularly associated with harbour porpoise bycatches in eastern Canada (Fontaine *et al.*, 1994a; Trippel *et al.*, 1999; Hood, 2001; this study). The distribution of Atlantic herring closely follows the 60m isobath in the Miscou Bank area and likely overlaps to some extent the distribution of Atlantic cod (LeBlanc *et al.*, 2002a; b). Harbour porpoises might have sought this abundant and rich food resource during late summer in the vicinity of the Miscou Bank, making them vulnerable to incidental mortalities in Atlantic cod fisheries. Two studies conducted in the Bay of Fundy and Newfoundland indicated a close relationship between harbour porpoise and Atlantic herring catch rates and support this hypothesis (Trippel *et al.*, 1999; Hood, 2001).

Bycatch estimates obtained through the mail survey and the at-sea observer programme both suggest a decrease in harbour porpoise bycatches since the late 1980s, although the magnitude of this change remains uncertain. The use of a survey area similar to Fontaine *et al.* (1994a) resulted in estimates from questionnaires 24-63% lower in 2000-2001 compared to the late 1980s (bycatch estimates = 1,907 [95% CI 1,235-2,579] and 1,762 [95% CI 563-3,251] harbour porpoises in 1989 and 1990, respectively; Fontaine *et al.*, 1994a). Using at-sea observer data and an area similar to Fontaine *et al.* (1994a), 500 individuals or fewer were probably caught in 2001 and 2002, representing a reduction in bycatch levels of at least 72-75% compared to the late 1980s. Although results from questionnaires suffer from a number of weaknesses associated with the method, the consistency in the areas identified as the most problematic for harbour porpoise bycatches between this study and two similar mail surveys conducted in the late 1980s and early 1990s lends confidence to the general trend observed since the late 1980s. The 24-63% reduction in bycatch levels

obtained through the questionnaire survey is probably more realistic than the 72-75% reduction suggested by the at-sea observer programme, given the incomplete and generally low coverage of the fishery by the latter programme. No comparisons were possible between bycatch estimates from our study and those obtained from a similar survey mailed in 1992 and 1993 (Larrivée, 1996) since the latter study was conducted over an undefined portion of the Estuary and Gulf of St. Lawrence. In addition, bycatch estimates in the latter study (i.e. mean estimates of 3,650 in both years, with 95% CI of 1,493-5,806 and 1,657-5,642 harbour porpoises in 1992 and 1993, respectively) were overestimates, since they were produced while assuming that all fishermen with valid licenses had been actively fishing in each of these years, which was most probably not the case (M. Larrivée, Centre spécialisé des pêches, C.P. 220, Grande-Rivière, Qc, pers. comm.).

Bycatch estimates obtained through questionnaires and the at-sea observer programme, although imprecise, indicate that the incidental mortality of harbour porpoises in the gillnet fishery of the Estuary and Gulf of St. Lawrence remained substantial in 2000-02 (i.e. mean estimates of 1,000-2,400 individuals per year), in spite of a decrease in the groundfish fishing activities and total bycatches compared to the late 1980s and early 1990s. Whether current removals are sustainable for the harbour porpoise population depends on a variety of factors, including population size and rate of increase (reviewed in Donovan and Bjørge, 1995; Hall and Donovan, 2002). The abundance of harbour porpoises in the Gulf of St. Lawrence was last assessed in 1995 and 1996 using systematic line-transect aerial surveys (Kingsley and Reeves, 1998). Sampling of a large portion of the Gulf of St. Lawrence in 1995 and its northern portion in 1996 yielded estimates of 12,100 (CV=26%) and 21,720 (CV=38%) harbour porpoises, respectively. Once corrections were applied to the estimates to account for visibility biases associated with observer experience, availability and detectability of porpoises, Kingsley and Reeves (1998) estimated that an average 36,000 to 125,000 porpoises occupied the Gulf of St. Lawrence during the summers of 1995 and 1996. In the absence of empirical measurements of population rate of increase for harbour porpoises, several studies attempted to estimate maximum rate of increase (R_{max}) for this species using mortality schedule of humans or other mammals. These exercises provided R_{max} varying between 4% and 10%, although some authors debated the validity of the higher values (reviewed in Stenson, 2003). Considering the lower and upper 95% confidence limits of our most reliable estimate of bycatch (i.e. the 2001 questionnaire survey results; Table 2), and assuming an R_{max} of 4%, the harbour porpoise population in the Gulf of St. Lawrence would need to be at least 36,000-83,700 individuals for current incidental catches to be sustainable. If the rate of increase is less than maximal, e.g. $0.5R_{max}$ or 2%, then 72,000-167,400 harbour porpoises would be needed to attain sustainability. Although the trajectory of the population since it was last surveyed in 1996 is uncertain, these findings suggest that bycatch levels might remain a cause for concern for the harbour porpoise population in the Gulf of St. Lawrence. An update of population estimates may assist in putting bycatch estimates into perspective. The differences observed in bycatch rates between the sentinel fisheries and commercial fisheries subjected to at-sea observations in NAFO area 4Tn indicate that slight changes in the spatial and temporal distribution of fishing activities might result in substantial changes in harbour porpoise incidental catches. Our results also emphasise the sensitivity of bycatch estimates to the spatial and temporal distribution of the effort by at-sea observers. Clearly, a better understanding of the seasonal and fine-scale spatial distribution of harbour porpoise bycatches would help mitigate the impacts of the commercial fisheries for groundfish on this harbour porpoise population. This goal might be achieved by the intensification of the at-sea observer monitoring programme in areas of the Gulf of St. Lawrence where harbour porpoises are known to be abundant, such as the Lower North Shore and zone 4R, and where much of the Atlantic cod gillnet fishery takes place.

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