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**Incidental mortality of harbour
porpoises in the gillnet fishery of the
Estuary and Gulf of St Lawrence in
2000-2002.**

**Prises accidentelles de marsouins
communs associées aux pêcheries au
filet maillant de l'estuaire et du golfe
du Saint-Laurent en 2000-2002.**

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Abstract

The incidental mortality of harbour porpoises as a by-catch of the gillnet fishery of the Estuary and Gulf of St Lawrence was evaluated using questionnaires to fishermen in 2000 and 2001, and At-sea Observers and Sentinel Fisheries programs in 2001 and 2002. Of the 2277 fishermen receiving the by-catch questionnaire, 215 (9%) responded, and 165 reported being actively fishing in 2000 or 2001. Of these, 34 (23%) and 45 (27%) fishermen recorded having taken a total of 181 and 291 harbour porpoises in 2000 and 2001, respectively. The largest takes were in July and August from zones 4R, Miscou and the North Shore. These takes resulted in mean by-catch rates of 1.25 (SD = 5.0) and 1.76 (SD = 4.7) porpoises per reporting fisherman in 2000 and 2001, respectively. Extrapolation of these by-catch rates to the entire gillnet fishing fleet resulted in an estimated total by-catch of 2180 (95% CI 1012–3802) and 2478 (95% CI 1591–3464) porpoises for the Estuary and Gulf of St Lawrence in 2000 and 2001, respectively.

For 2001 and 2002, a total of 786 and 882 bottom-set gillnet hauls that were monitored by At-sea observers recorded harbour porpoise by-catches of 4 and 6 individuals, respectively. At-sea observer activities were conducted in close conjunction with the Atlantic cod and Greenland halibut commercial fishery. However, the low number of hauls that were monitored by At-sea observers prevented the calculation of by-catch estimates for several zones and the study area as a whole, and provided only imprecise estimates for all other zones. Sentinel fisheries resulted in 86 and 77 by-catches in 2001 and 2002, respectively. Depending on the year, incidental takes of harbour porpoises by this fishery peaked in late August or early September, even though their activity peaked earlier, in late July to late August in 2001 and 2002, respectively. The number of takes per haul for the Sentinel fishery was higher than that reported through the At-sea Observer program, even though the former was spread over a longer period, when target species of the fishery might have been less abundant. Significant differences in fishing behaviour were observed between commercial fisheries, commercial fisheries with At-sea observers on board, and Sentinel fisheries. Specifically, Sentinel fisheries soaked nets of similar length but of smaller mesh, at deeper depths, for longer periods, and for a lesser quantity of landed fish than was the case for commercial fisheries with an observer on board. In addition, plotting the fishing locations in the Miscou area (NAFO 4Tn) indicated that at least in August and early September 2001, not only was there no overlap in fishing location between Sentinel fisheries and commercial fisheries under the At-Sea Observer program, but there was also no overlap between commercial fisheries with observers on board and commercial fisheries not subject to an at-sea observation. Commercial and Sentinel fisheries generally followed the 60-m isobath, whereas fishing activities with At-sea observers on board occurred in shallower waters, inside 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.

Résumé

Les mortalités accidentelles de marsouins communs associées aux pêcheries au filet maillant de l'estuaire et du golfe du Saint-Laurent ont été évaluées à l'aide de questionnaires distribués aux pêcheurs en 2000 et 2001, et à l'aide des programmes d'Observateurs en mer et de Pêcheries Sentinelles en 2001 et 2002. Des 2277 pêcheurs qui ont reçu un questionnaire, 215 (9%) ont répondu, desquels 165 ont rapporté avoir pêcher activement en 2000 ou 2001. De ceux-ci, 24 (23%) et 45 (27%) pêcheurs ont rapporté avoir pris un total de 181 et 291 marsouins en 2000 et 2001, respectivement. Les plus imposantes prises sont survenues en juillet et août dans les zones 4R, Miscou et Côte-Nord. Ces prises se sont traduites en des taux moyen de prises accidentelles de 1.25 (ET = 5.0) et 1.76 (ET = 4.7) marsouins par répondant en 2000 et 2001, respectivement. L'extrapolation de ces taux de prises accidentelles à la flotte entière de pêcheurs au filet maillant a résulté en une estimation globale de 2180 (95% IC 1012–3802) et 2478 (95% IC 1591–3464) marsouins pour l'estuaire et le golfe du Saint-Laurent en 2000 et 2001, respectivement.

En 2001 et 2002, un total de 4 et 6 marsouins ont été rapportés avoir été pris lors du monitoring de 786 et 882 traits de filets maillants fixes par les Observateurs en mer. Les activités des Observateurs en mer se sont déroulées en association étroite avec celles des pêcheries commerciales à la morue franche et au turbot. Toutefois, le faible nombre de traits qui ont été monitorés par les Observateurs en mer a prévenu le calcul d'une estimation des prises accidentelles pour plusieurs zones et globalement pour l'aire d'étude, et a résulté en des estimations imprécises pour les autres zones. Les Pêcheries Sentinelles a résulté en 86 et 77 prises accidentelles en 2001 et 2002, respectivement. Selon les années, les prises accidentelles de marsouins communs associées à la pêche ont culminées à la fin août ou au début septembre, malgré une intensité maximale d'activité de cette pêcherie à une période plus précoce de la fin juillet à la fin août en 2001 et 2002, respectivement. Le nombre de prises accidentelles par trait rapporté par les Pêcheries Sentinelles était plus élevé que celui rapporté par le programme des Observateurs en mer et ce, malgré une activité des Pêcheries Sentinelles étendue sur une période plus longue, où les espèces visées par les pêcheries ont pu être moins abondantes. Des différences significatives ont été observées dans la manière de pêcher entre les pêcheries commerciales, les pêcheries commerciales faisant l'objet d'Observations en mer, et les Pêcheries Sentinelles. Plus spécifiquement, Les Pêcheries Sentinelles ont mouillé des filets de longueur similaire mais de vide de maille plus faible, à des profondeurs plus grandes, pour des périodes plus prolongées, et pour une quantité de poisson débarqué plus faible que les pêcheries commerciales sujettes à de l'Observation en mer. De plus, la superposition des sites de pêches dans le secteur de Miscou (NAFO 4Tn) indique qu'au moins en août et début septembre 2001, non seulement n'y avait-il aucun chevauchement des sites de pêche entre les Pêcheries Sentinelles et les pêcheries commerciales, mais il n'y avait non plus aucun chevauchement entre les pêcheries commerciales sujettes à l'observation et celles non sujettes à l'observation en mer. Les pêcheries commerciales et Sentinelles épousaient généralement l'isoligne de 60 m, alors que les pêcheries commerciales sujettes à l'observation en mer se déroulaient en eaux moins profondes, à l'intérieur du banc de Miscou. En 2002, les périodes d'activité des observateurs en mer et des pêcheries Sentinelles dans la zone 4Tn ne se sont pas chevauchées dans le temps, mais se sont chevauchées dans l'espace.

Introduction

The harbour porpoise (*Phocoena phocoena*) is a species particularly vulnerable to incidental mortality in fishing gear. Interactions between harbour porpoises and fisheries have been observed world-wide, and are most often associated with fisheries using fixed gear, such as gill nets (Gaskin 1984; Read and Gaskin 1988; Smith et al. 1993; Perrin et al. 1994; Larrivée 1996; Trippel et al. 1996; Berggren et al. 2002; Stenson in press).

Harbour porpoises are widely distributed in temperate coastal waters of the northern hemisphere (Gaskin 1984). The species occurs at least seasonally in the Estuary and Gulf of St Lawrence (Fisher and Harrison 1970; Laurin 1976; Fontaine et al. 1994a; Larrivée 1996; Kingsley and Reeves 1998). Analyses of genetics and contaminant profiles suggest that individuals from this region could constitute a distinct population, although the Laurentian Channel might act as a physical barrier, separating sub-populations in the Gulf of St Lawrence (Gaskin 1984; Wang et al. 1996; Rosel et al. 1999; Tolley et al. 2001). Sergeant et al. (1970) referred to harbour porpoises as being moderately common in the Estuary and Gulf of St Lawrence. An aerial survey conducted at the end of July and in August 1995 and 1996 over a large portion of the Gulf of St Lawrence estimated that between 12,000 and 21,000 harbour porpoises occurred in this area during summer (Kingsley and Reeves 1998). These estimates were uncorrected for submerged animals that were missed during the aircraft overflight and thus, represent minimal estimates.

Laurin (1976) was the first to point out that incidental catches of harbour porpoises might represent a non-negligible source of mortality for this species in the Gulf of St Lawrence. Studies conducted during the late 1980s and early 1990s indicated substantial by-catches of harbour porpoises in the groundfish gillnet fisheries of the Gulf of St Lawrence (Fontaine et al. 1994a; Larrivée 1996). These takes were thought to approach or exceed levels sustainable by the population. Similar concerns were raised for harbour porpoises off Newfoundland, and for other populations in the Northwest Atlantic, including West Greenland and Bay of Fundy / Gulf of Maine (Gaskin 1984; Read and Gaskin 1988; Bravington and Bisack 1996; Bisack 1997; DFO 2001). Consequently, the species was listed as *Threatened* in eastern Canada by the Committee on the Status of Endangered Wildlife in Canada in 1990 (Gaskin 1992). The species is also protected under the Marine Mammal Protection Act of 1972 in eastern United States.

During the period following these studies, several groundfish stocks collapsed in the Northwest Atlantic, leading to major reductions and even complete closures of several fisheries after 1993. These reductions in groundfish fishery activities are suspected to have had beneficial impacts on harbour porpoise populations by reducing rates of incidental mortality. Some indications of these reductions in by-catch levels are available for the Bay of Fundy / Gulf of Maine population (Rossman and Merrick 1999; Waring et al. 2001; reviewed in Read 2003). However, similar studies have not been conducted in the Estuary and Gulf of St Lawrence or Newfoundland following the profound changes to the groundfish fisheries. Consequently, current impacts of groundfish fisheries on harbour porpoises from the Gulf of St Lawrence are largely unknown.

The objective of this study was to describe the distribution and level of gillnet fishing activity in the Estuary and Gulf of St Lawrence in 2000–2002, and to provide an estimate of incidental mortality of harbour porpoises in this fishery. An approach similar to that used in the late 1980s and early 1990s, *i.e.* questionnaires sent to gillnet fishermen, was used in order to allow comparisons between estimates from the two periods (Fontaine et al. 1994a; Larrivée 1996). However, as by-catch estimates obtained through questionnaires suffer from numerous problems, an additional approach, using independent observers onboard of fishing vessels, was used to calculate another estimate of incidental takes of harbour porpoises for 2001 and 2002 (Lien et al. 1994; Bravington and Bisack 1996; Trippel et al. 1996; Bisack 1997).

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. Information on incidental catches of harbour porpoises in fishing gear was obtained using two different approaches: 1) questionnaires mailed out to fishermen after their fishing season had ended, and 2) data collected directly from fishing vessels, either by the fishermen themselves or by independent observers.

Questionnaires

A list of fishermen from the Estuary or Gulf of St Lawrence, with valid groundfish, Atlantic herring or mackerel gillnet fishery licenses in year 2000 was obtained from Fisheries and Oceans Canada, Division of Statistics and Data Processing in the spring of 2001. Fishermen that had valid licenses in 2000 were assumed to have had maintained their licenses through 2001. Questionnaires were sent to a random sample of 2277 fishermen during October-December 2001, inquiring as to fishing activities and by-catches of marine mammals during the two preceding fishing seasons, *i.e.* 2000 and 2001. Fishermen were asked the same questions as those formulated by Fontaine *et al.* (1994a), *i.e.* number of harbour porpoises caught during 2000 and 2001, month of capture, type of fishing gear, location of capture. They were also asked to report observations of harbour porpoises, incidental takes of other marine mammals, damage to fishing gear, and their impressions on the trends of populations of harbour porpoises and seals. Only information related to harbour porpoise by-catches will be presented in this report.

Data obtained directly from fishing vessels

At-sea Observer program

An At-Sea Fisheries Observer Program has been in place in the Gulf of St Lawrence since the early 1980s. This program 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 information on by-catches of marine mammals. Prior to 2001, observers in Areas 4S and 4T were instructed to take notes of catches and discards using predefined coding for the different species of fish and invertebrates. Marine mammal by-catch information was noted in the remarks section, but was probably not noted systematically since observers were not instructed to pay attention to marine mammal by-catches *per se*. In 2001 and 2002, coding for each species of marine mammals was added to the datasheets, and the importance of noting marine mammal by-catches was emphasised by a DFO representative during annual training sessions of observers. In Area 4R, datasheet coding for harbour porpoise by-catches has been in place for some time already, with by-catches of any marine mammals being routinely and consistently over the years (D. Kulka, Northwest Atlantic Fisheries Centre, St. John's, Nfld, personal communication). When not specified in the remarks section, the number of harbour porpoises incidentally taken during a haul was estimated from the reported mass, assuming a mean mass per individual of 50-60 kg (Read and Tolley 1997).

The At-sea observer program coverage varied with the type of fishery. According to conservation harvesting plans, 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 2001 and 2002. Coverage should also have been at least 5% for the fixed gear Greenland halibut (*Reinhardtius hippoglossoides*) and winter flounder (*Pleuronectes americanus*) fisheries. No coverage was made of the fixed gear fishery for American plaice (*Hippoglossoides platessoides*) and witch flounder (*Glyptocephalus cynoglossus*).

Sentinel Fishery program

The Sentinel Fishery program for the Gulf of St Lawrence has been initiated in 1994. This program is not intended to monitor commercial fishing activities. Rather, its main objective consists in obtaining

information on population trends of commercially-valuable but non-abundant species, using predefined scientific fishing protocol and gear type. Fishermen may be asked to deploy their fishing gear in non-traditional fishing areas during periods of low abundance or concentration of targeted fish species. Information collected in the context of Sentinel fisheries is very similar to that collected during the At-sea Observer program, and include records of marine mammal incidental takes, in addition to measurements or sampling of targeted species. In Area 4T, all fixed gear Sentinel fishing vessel has an observer present when catches are hauled on board. This observer handles the data collection and fish sampling. 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 Program in Areas 4R, 4S and 4T.

Total fishing effort and estimation of harbour porpoise by-catch rates

An index of commercial fishing activities was obtained from information on total landings of all fish species in terms of 'live' kilograms of fish caught before processing, through purchase slips, logbooks, and dock-side monitoring. This database also provided information on target species and type of fishing gear, but only partial information on fishing location, fishing gear, soak time, etc., since logbooks are not mandatory for smaller vessels and some types of fishery.

Several different units have been used to estimate by-catch rates and quantify fishing effort, including individual fisherman, landing, trip, haul, net length, soak time, or a combination of the latter two (Read and Gaskin 1988; Bravington and Bisack 1996; Trippel et al. 1996; Bisack 1997). However, there is as yet no consensus as to which of these measures represents the best unit of effort to describe by-catch rates of marine mammals (Palka 1994). The choice of a haul rather than a trip as a unit of effort eliminates the variability associated with the number of hauls per trip. The number of by-caught harbour porpoises appears to be related to the net length and to a certain extent the soak time, but not necessarily the landings (Hood 2001; DFO 2001). Kilometres of nets represents a measure commonly used in fisheries to estimate effort (Chadwick et al. 1990). Landings have also commonly been used to quantify fishing activity since they are often the only information consistently available from commercial fisheries. The use of units other than landings to measure fishing effort and expand by-catch rates to the entire fishing fleet requires that mean landings per unit of effort (e.g. per haul, trip, km of nets, etc.) be obtained from another source of data (e.g. At-sea Observer or Sentinel Fishery program) and be divided into corresponding total landings using commercial fishery information (Bravington and Bisack 1996).

An active fisherman was chosen as the unit of effort for calculation of by-catch estimates of harbour porpoises using the questionnaires. In other words, by-catch estimates were expressed as a number of by-caught porpoises per respondent. A fisherman was considered active if he had landed fish at least once during the fishing season. An estimate of the total number of harbour porpoises that were by-caught during a given year in the Estuary and Gulf of St Lawrence was obtained by extrapolating the average by-catch rate to the total number of active gillnet fishermen during that year.

A haul was used as an estimate of activity by At-sea Observers and Sentinel Fisheries, and was defined as the retrieval of a string of nets. Total landings per haul was used as the unit of effort for At-sea Observer and Sentinel Fishery activities. This measure of effort from the At-sea Observer program was used to back-calculate from fish landings fishing effort by the fisheries industry, and obtain estimates of harbour porpoise by-catch rates. As observer coverage was low in several zones, mean landings per haul was calculated globally and not per zone for each target species and year. Standard bootstrap techniques were used to calculate coefficients of variation and 95% confidence intervals for the by-catch estimates.

Stratification scheme

Differences were expected 1) between years in fish and harbour porpoise abundance and distribution (Chouinard et al. 2001; 2002; Waring et al. 2001), and 2) between Sentinel and At-Sea Observer fisheries in fishing location and period (see above). Consequently, an initial stratification of the

data was established based on year and methodology of data collection (At-Sea Observer program vs Sentinel program vs questionnaires). Data was further stratified, based on the spatial distribution and intensity of fishing relative to NAFO areas, resulting in five zones: North-western Gulf, Miscou, Southern Gulf, North Shore, and 4R (Figure 1-4). The Greenland halibut and Atlantic cod fisheries were considered separately, since the fishery for Greenland halibut typically occurred in deep waters of the Laurentian, Honguedo and Esquiman channels, in contrast to the Atlantic cod fishery which mostly operated in shallower waters (Figure 1-4). Location of fishing activities as presented from these figures provides only a partial overview of the entire fishery for these species, since fishing location information was obtained from one of three possible sources of information in the commercial fishery database (*i.e.* logbooks), and logbooks are mandatory only for larger vessels in some NAFO areas (*e.g.* logbooks are not mandatory for vessels 45 ft or less in Area 4T for the Greenland halibut fishery). The low levels of activity by At-sea Observers precluded any temporal stratification of the data.

The low response rate also precluded any stratification of the data when calculating by-catch rates using the questionnaires. Active fishermen in the different NAFO areas were assumed to have had an equal chance of receiving or completing and returning the questionnaire, *i.e.* the number of answers that were received was proportional to the number of active fishermen in each NAFO area. One way of verifying this assumption would have consisted in re-sampling of both respondents and non-respondents shortly after questionnaires were returned, thus minimizing the chance of inconsistencies in information due to difficulties of their recollection of events over time. However, this verification could not be done in a timely fashion following the reception of questionnaires.

Results

Gillnets were the only gear responsible for the incidental mortality of harbour porpoises in this study (see below). Consequently, other types of gear (*e.g.* longlines) will not be dealt with any further in this document.

Fishing activities in 2001 and 2002

A total of 786 and 882 bottom-set gillnet hauls were monitored by At-sea Observers in 2001 and 2002, respectively. Fisheries targeted by the At-sea Observer program were in decreasing order of importance Atlantic cod, Greenland halibut, winter flounder and American plaice (Table 1). Fishing activities for Atlantic cod occurred mainly in zones 4R and Miscou, whereas the Greenland halibut fishery occurred almost exclusively in the northern Gulf (*i.e.* North-western Gulf and North Shore) and along the west coast of Newfoundland (zone 4R) (Table 1; Figures 5–8). Fishing activities for Atlantic cod were at least twice as intense in Area 4R as they were in Miscou during both 2001 and 2002. However, the number of hauls monitored by At-sea Observers in Miscou was 3 to 4 times higher than in 4R, resulting in a stable coverage of about 9% in Miscou, as compared to less than 1% in 4R. While the intensity of cod fishing activities was comparable for both the North Shore and in the Southern Gulf, coverage by At-sea Observers was nearly null in the former, and at least 6% in the latter. Similarly, coverage of the Greenland halibut fishery by At-sea Observers was relatively high (7-17%) in North-western Gulf, but nearly null along the North Shore and in 4R where high levels of halibut fishing occurred in both years. The winter flounder fishery concentrated in zones 4R, Miscou and Southern Gulf, whereas the American plaice fishery occurred almost exclusively in zone 4R. The number of hauls observed for both these fisheries was low in 2001 and 2002, resulting in variable percent coverage.

The At-sea Observer activities followed relatively closely those of the commercial fishing industry for both Atlantic cod and Greenland halibut fisheries. Most of the At-sea Observer effort for the cod fishery occurred early and late in the season (late July and late September) in the Southern Gulf when took place most of the fishing activity, whereas Observer efforts occurred mainly in July and early August in the more northerly areas of the Gulf (Figure 5). Similarly, At-sea Observer efforts were the highest during periods when most of the commercial fishing activity for Greenland halibut took place in North-western Gulf and 4R, and along the North Shore, *i.e.* mainly between early July and late September (Figure 6).

The Sentinel Fishery program was oriented exclusively towards Atlantic cod in 2001 and 2002 (Table 1). The spatial distribution of this fishery appeared to be independent to the commercial industry. Sentinel Fishery activities were highest along the North Shore with a steady 100 hauls per year, even so commercial fishing activity for Atlantic cod was low in this area compared to Miscou and 4R. Similarly, appreciable levels of Sentinel Fisheries occurred in the Southern Gulf in 2002 in spite of little activity in the way of commercial fishing in this sector. Only for the North-western Gulf were Atlantic cod Sentinel and commercial fishery activities low during both years. In addition, and in contrast to the At-sea Observer program which peaked at the same period as the commercial fishery, Sentinel Fisheries remained highly active over extended periods, and included areas and periods with little or no commercial fishery activities (Figure 5).

Incidental takes of harbour porpoises in 2000-2002

Questionnaires

Fifty-seven percent of the 2277 questionnaires were mailed to fishermen that possessed either a groundfish gillnet fishery license (n = 230) or both a groundfish gillnet license and a herring or mackerel gillnet license (n = 1064). The remaining 983 questionnaires (43%) were mailed to fishermen with only a herring or mackerel gillnet fishery license (Table 2). A total of 165 of 215 respondents were active during 2000 or 2001 and accepted to provide information on marine mammal by-catches. Response rates from groundfish fishermen (57%) and those who possessed only a herring or mackerel gillnet license (43%) were proportional to the number of questionnaires assigned to each group.

A total of 181 and 291 harbour porpoises were taken by 34 fishermen (23%) and 45 fishermen (27%) in 2000 and 2001, respectively (Figure 9). These takes were reported from different zones of the Gulf of St Lawrence (Figures 10-11). Zones 4R, Miscou and the North Shore were responsible for the largest by-catches, whereas the North-western Gulf, and particularly the St Lawrence Estuary portion of this area, accounted for a relatively small number of incidental takes. The number of by-catches was highest in July and August during both 2000 and 2001, although they remained high during September in 2001 (Figure 12). Atlantic cod, herring and mackerel were the species most often associated with by-catches of harbour porpoises during both 2000 and 2001 (Table 3).

These takes resulted in mean by-catch rates of 1.25 (SD = 5.0) and 1.76 (SD = 4.7) porpoises per reporting fisherman in 2000 and 2001, respectively. Mean catch rates did not differ significantly between years ($t = -0.62$, $p > 0.05$). Extrapolation of these by-catch rates to the entire active fishing fleet using bottom-set gillnets resulted in an estimated total by-catch of 2180 (95% CI 1012–3802) and 2478 (95% CI 1591–3464) 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) provided estimates of 1343 (95% CI 441–2702) and 717 (95% CI 340–1204) harbour porpoise by-catches in 2000 and 2001, respectively.

At-sea Observer and Sentinel Fisheries programs

A total of 10 harbour porpoise by-catches were reported by At-sea Observers in 2001 (n = 4) and 2002 (n = 6) (Table 1). Atlantic cod and Greenland halibut bottom set gillnet fisheries were responsible for seven and three of these catches, respectively. At least six of seven harbour porpoises taken by the Atlantic cod fishery in the different zones of the Gulf were caught in late July when most of the At-sea Observer activities took place; the date of by-catch was unavailable for an animal taken in zone 4R. The three incidental mortalities associated with the Greenland halibut fishery occurred in North-western Gulf in 2002, and were spread out in time between late July and early September (Figure 13a). Harbour porpoises by-caught in the Atlantic cod fishery were generally taken in waters less than 60 m deep, whereas at least two of the three captures associated with the Greenland halibut fishery were taken at deeper depths (Figure 14: NAFO Areas 4Tq and 4To). The low number of hauls that were monitored by At-sea Observers prevented the calculation of by-catch estimates for several zones and the study area as a whole, and provided only imprecise estimates for all other zones (Table 4).

Sentinel Fishery activities resulted in 86 and 77 by-catches of harbour porpoise in 2001 and 2002, respectively (Table 1, 5). Depending on the year, incidental takes of harbour porpoises by this fishery peaked in late August or early September, even though their activity peaked earlier in the season, in late July to late August in 2001 and 2002, respectively (Figure 13b). Between 53 and 65% of these catches occurred in zone Miscou, whereas most of the other takes were reported in zone 4R and along the North Shore (Table 5).

The number of takes per haul for the Sentinel Fishery was higher than that reported through the At-sea Observer program (Table 4-5). By-catch rates were higher in Sentinel than Observer fisheries, even though the activity of the former was spread over a more extended period, when target species of the fishery might have been less abundant. The large number of by-catches ($n=31$ for 14 hauls in 2001, $n=48$ for 19 hauls in 2002) observed in the Sentinel Fishery on Miscou banks (NAFO area 4Tn) compared to that reported through the At-sea Observer program ($n=0$ in 313 and 212 hauls in 2001 and 2002, respectively) was puzzling. The vast majority (26/31 and 46/48) of the takes by the Sentinel Fishery occurred in late August and September when activities by commercial cod fisheries had decreased (Figure 5). Commercial fisheries activities were nearly null and coverage by At-sea Observers, non-existent during this period in 2002, which might explain why no harbour porpoises were reported for that year. During the same period in 2001, 37 hauls were subjected to an At-sea Observer monitoring. A comparison of different parameters related to operations, including fishing depth, number of gear, soak time and fishing location, for periods when both types of activity occurred at the same period (August and early September), revealed significant differences in fishing behaviour between commercial fisheries, commercial fisheries with At-sea Observers on board, and Sentinel fisheries. Specifically, Sentinel fisheries soaked nets of similar length but of smaller mesh, at deeper depths, for longer periods, and for a lesser quantity of landed fish than was the case for commercial fisheries with an observer on board (Table 6). Plotting the cod fishing locations in the Miscou area (NAFO 4Tn) indicated that, at least for August and early September 2001, not only there was no overlap in fishing location between Sentinel fisheries and commercial fisheries under the Observer program. Additionally, there was no overlap between commercial fisheries with observers on board, and commercial fisheries not subject to an at-sea observation (Figure 15). Commercial and Sentinel fisheries generally followed the 60-m isobath, whereas fishing activities with At-sea observers on board occurred in shallower waters, inside 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 (Figure 16).

Discussion

The At-sea Observer program and the mail survey provided contradictory indices of by-catch levels of harbour porpoises in the Estuary and Gulf of St Lawrence. On the one hand, At-sea Observer data suggested that harbour porpoise by-catches were in the low hundreds in 2001 and 2002. In contrast, questionnaires to fishermen estimated a total by-catch of 2180 and 2478 harbour porpoises in 2000 and 2001, respectively. The use of a survey area similar to Fontaine et al. (1994a) resulted in estimates of 1343 and 717 harbour porpoises for 2000 and 2001, respectively. In comparison, Fontaine et al. (1994) had estimated a total by-catch of 1907 (95% CI = 1235–2579) and 1762 (95% CI 563–3251) harbour porpoises in 1989 and 1990, respectively. In a similar study conducted over an undefined portion of the Gulf of St Lawrence, but which included the Estuary and northern Gulf of St Lawrence and the Magdalen Islands, Larrivée (1996) had estimated a total by-catch of 1493–5806, and 1657–5642 harbour porpoises in 1992 and 1993, respectively (means estimates of 3650 in both years). However, these estimates were produced while assuming that all fishermen with valid licenses had been actively fishing in each of these years, which might not have been the case (M. Larrivée, personal communication, 9 Dec. 2002). Consequently, the results from questionnaires would indicate a 20–60% reduction in incidental takes of harbour porpoises since the late 1980s, whereas the At-sea Observer program would indicate levels of harbour porpoise by-catch in 2001 and 2002 approaching only one quarter of those documented in the late 1980s.

The two approaches that were used in this study to estimate by-catch levels were liable to be affected by several issues. In contrast with the study by Fontaine et al. (1994a) which surveyed all active fishermen, this study questioned an unknown fraction of active fishermen. In addition, this study

assumed in its estimation of total by-catches that the random sample of fishermen who received a questionnaire were distributed in the different zones of the study area proportionally to the level of fishing activity in each zone. Return rates of questionnaires in the study by Fontaine et al. were 33% and 18% for 1989 and 1990, respectively. These rates were considered low, and the reliability of by-catch estimates derived from surveys with low response rates was questioned by participants to a workshop (Palka 1994). The return rate in the study by Larrivée (1996) was 17%. The return rate in this study was even lower (13%). Considering that 17% of the respondents were inactive (Table 2), response rates might have been higher if only active fishermen had been questioned. Finally, this study and others of the same type were subject to diverse biases associated with the willingness of fishermen to transmit information that might impede their future fishing activities. Surveys also suffer from the capacity of fishermen to recall events that took place several weeks or even months earlier (Lien et al. 1994). Questionnaires in this study in the months following the end of the fishing season, which has helped to reduce the latter bias. While fishermen were asked to provide information on harbour porpoises taken incidentally over the past two seasons, those by-catch estimates from the fishing season just preceding the distribution of questionnaires (2001) were considered the most reliable.

The zones identified as being associated with high levels of by-catch differed between the two sources of information used in this study (questionnaires to fishermen and the At-sea observer and Sentinel Fishery programs). Fontaine et al. (1994a) and Larrivée (1996) had both identified the Gaspé Peninsula (NAFO Areas 4Tn and 4To), and Lower North Shore (4Sv and 4Sw) as important areas of by-catch of harbour porpoises. The Sentinel Fishery program and the questionnaires, but not the At-sea Observer data, confirmed the importance of these areas for incidental takes of harbour porpoises (Figures 10-11; Table 1). The absence or low coverage of the Atlantic cod fishery by At-sea Observers along the North Shore, and to a lesser extent in Area 4To may in part explain the absence of reports of by-catches in these sectors. In contrast, coverage of commercial fisheries by At-sea Observers in Area 4Tn was high during both years. Consequently, the absence of by-catches in this area is unlikely to be attributable to the intensity of observation on the fishery.

The use of an independent observer, ideally dedicated to marine-mammals (so called 'on-watch') is recognized as being the most desirable approach for obtaining information on levels of by-catch of marine mammals (Perrin et al. 1994; Trippel et al. 1996; Bisack 1997; DFO 2001). However, the amount and distribution of observer coverage must be adjusted so as to ensure the detection of a reasonably high number of events, and thereby the achievement of an acceptable coefficient of variation. 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 North-western Gulf and Atlantic cod fishery in zone Miscou (Table 1). Consequently, the reliability of by-catch estimates from the observer program is questionable.

There are several lines of evidence indicating that by-catch rates may have been underestimated by the At-sea Observer program. The most striking evidences come from the Miscou area (NAFO Area 4Tn). This sector was identified as one of the most problematic areas for by-catches of harbour porpoises 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 by-catches reported by fishermen through questionnaires in 2000 and 2001, respectively, and 62–65% of incidental mortality reported by the Sentinel Fishery in 2001 and 2002. However, no harbour porpoise by-catches were detected by At-sea Observers in 2001 and 2002 in spite of the high number of monitored hauls (Table 1). Inconsistencies in data collection between observers is unlikely to be the reason for this discrepancy since the same individuals served as observers onboard Sentinel or At-sea Observer fishery vessels (M. Jean, Biorex Inc., Caraquet, pers. comm.). An experimental study conducted by Larrivée (1996) between May and August 1992 in Area 4Tn indicated a mean by-catch rate of 3.85 harbour porpoises per landed tonne of fish. Boldly applying this rate towards all the landings reported in this area in 2001 (705 tonnes) and 2002 (496 tonnes) would have yielded estimated by-catches of 2714 and 1910 harbour porpoises, respectively, for Area 4Tn alone. The by-catch rate obtained by Larrivée is unlikely to hold for the current situation in Area 4Tn given the profound changes observed in Atlantic cod abundance, fishing period, and number of operating fishing vessels. However, the results from this simple calculation suggest that a meticulous examination of the data available for this area is certainly 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 by-catch of harbour porpoises. Fisheries that occurred later in the season (late August and September) and closer to the 60-m isobath appeared more susceptible to cause incidental mortality of harbour porpoises (Figures 13, 15). Larrivée (1996) obtained similar results in a controlled fishing experiment between the 36-m and 55-m 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 by-catches of harbour porpoises. Consequently, a larger effort by At-sea Observers, closer to the 60-m isobath where most of the commercial fisheries activity occurred might have revealed higher by-catch estimates in 4Tn. The difference that was observed in 2001 in the spatial distribution between commercial fisheries subjected and not subjected to an observer monitoring suggests that fishermen may behave differently in the presence of At-sea Observers. This pattern was not observed in 2002, and was not investigated for other zones.

The increase in harbour porpoise by-catches in late summer might be related to an influx of harbour porpoises inshore, possibly related to an increase in the abundance of Atlantic herring in coastal waters of Baie des Chaleurs (LeBlanc et al. 2001; 2002). This species, which spawns in the spring and fall, represented an important prey of harbour porpoises in zone Miscou both in the late 1980s and in 2001–2002 (Fontaine et al. 1994b; Guimont 2003). This species was also regularly associated with by-catches of harbour porpoises (Fontaine et al. 1994a; Hood 2001; this study). The distribution of Atlantic herring follows closely the 60-m isobath, and likely overlaps to some extent with the distribution of Atlantic cod (LeBlanc et al. 2001; 2002; Figures 15-16). Therefore, harbour porpoises may have been seeking this abundant and rich food resource during late summer in the vicinity of the Miscou bank, which in turn made them vulnerable to incidental catches in Atlantic cod fisheries.

The fact that observers onboard vessels monitored under the Sentinel or At-sea Observer program were not entirely dedicated to marine mammal watch, and might have resulted in an underestimation of incidental takes of harbour porpoises. Studies which compared takes reported by At-sea Observers while they were 'on-watch' and 'off-watch' for marine mammals, *i.e.* while they were actively or not seeking for harbour porpoises while nets were being hauled in, indicated that a non-negligible (about 18–37%) proportion of by-caught harbour porpoises fall out of the net before being brought back on deck (Palka 1994; Bravington and Bisack 1996).

In conclusion, by-catch estimates obtained through questionnaires and the At-sea Observer program, although imprecise, indicate that the incidental mortality of harbour porpoises in the gillnet fishery of the Estuary and Gulf of St Lawrence has remained non-negligible in 2000–2002, in spite of a reduction in groundfish fishery activities. Both indices suggest that the number of harbour porpoise by-catches have likely decreased since the late 1980s, but the magnitude of this change remains uncertain. The results obtained from Sentinel fisheries and commercial fisheries subjected to At-sea observations in NAFO area 4Tn suggest that finely-scaled temporal and spatial changes in fishing activities might result in dramatic changes in the incidental takes of harbour porpoises. These aspects should be investigated further by intensifying At-sea Observer monitoring in areas of the Gulf of St Lawrence where harbour porpoises are known to be present, such as the Lower North Shore and Area 4R, where much of the Atlantic cod fishery takes place.

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Table 1. Distribution of At-sea observer and Sentinel fishery effort (number of hauls) relative to fishery activities in the different zones and types of sink gillnet fishery in 2001 and 2002.

Target species	Zone	N commercial hauls		N observed hauls		Coverage observer (%)		N Sentinel hauls		N Harbour porpoises (n hauls)			
		2001	2002	2001	2002	2001	2002	2001	2002	Observers		Sentinels	
										2001	2002	2001	2002
Atlantic cod	North-western Gulf	9	60	1	1	10.9	1.0	22	12	0	0	0	0
	North Shore	1428	2529	1	17	0.1	1.0	539	457	0	1 (1)	26 (14)	14 (7)
	4R	8814	9404	70	80	0.8	0.9	512	403	1 (1)	0	11 (6)	13 (7)
	Miscou	3887	2522	362	232	9.3	9.2	195	329	0	2 (2)	46 (27)	50 (21)
	Southern Gulf	1116	139	67	48	6.0	34.5	135	233	3 (3)	0	3 (2)	0
Greenland halibut	North-western Gulf	2686	2835	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	4716	4047	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	-	-	-	-	-	-	-	-	-	-
Winter flounder	North-western Gulf	0	0	-	-	-	-	-	-	-	-	-	-
	North Shore	0	0	-	-	-	-	-	-	-	-	-	-
	4R	115	48	0	1	0	2.0	0	0	-	0	-	-
	Miscou	376	76 ^a	14	0	3.7	0	0	0	0	-	-	-
	Southern Gulf	389	5	12	4	3.1	77.8	0	0	0	0	-	-
American plaice	North-western Gulf	0	0	-	-	-	-	-	-	-	-	-	-
	North Shore	0	0	-	-	-	-	-	-	-	-	-	-
	4R	816	115	41	12	5.0	10.4	0	0	0	0	-	-
	Miscou	9	7 ^a	8	0	84.4	8.0	0	0	0	-	-	-
	Southern Gulf	0	0	-	-	-	-	-	-	-	-	-	-

^a Estimation based on species annual mean landing per haul

Table 2. By-catch estimates of harbour porpoises during 2000 and 2001, calculated from a mail survey of fishermen with gillnet licenses valid in 2000 for groundfish, Atlantic herring or mackerel in the Estuary or Gulf of St Lawrence.

	Estuary and Gulf of St Lawrence		Area similar to Fontaine et al. 1994a	
	2000	2001	2000	2001
Questionnaires sent (Fishermen with valid licenses in 2000)	2277			
Questionnaires returned	286 (13%)			
Questionnaires returned by inactive fishermen	36			
Questionnaires returned by active fishermen unwilling to participate	35			
N of fishermen willing to participate	215 (9%)			
Questionnaires with information on by-catch of harbour porpoises	145	165	76	86
Fishermen who caught harbour porpoises	34 (23.4%)	45 (27.3%)	18 (23.7%)	20 (23.3%)
Total number of harbour porpoise by-catches ^a	181	291	131	131
Mean (\pm SD) number of harbour porpoises per fisherman	1.25 \pm 5.0 ^b	1.76 \pm 4.7 ^b	1.72 \pm 6.6	1.52 \pm 4.3
	[0.58–2.18]	[1.13–2.46]	[0.59–3.46]	[0.72–2.55]
N of active gillnet fishermen	1744	1408	781	472
Extrapolation of the number of by-catches and [95% CI]	2180	2478	1343	717
	[1012–3802]	[1591–3464]	[461–2702]	[340–1204]

^a Assuming a by-catch of 1 harbour porpoise for fishermen who indicated 'some by-catches'

^b Between-year differences were non significant (*t*-tests, *p* > 0.05)

Table 3. Species associated with incidental takes of harbour porpoises during 2000 and 2001, as revealed by a mail survey of fishermen from the Estuary and Gulf of St Lawrence with gillnet licenses valid in 2000 for groundfish, herring or mackerel.

Species associated with harbour porpoise by-catches	2000		2001	
	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

Table 4. Estimates of incidental takes of harbour porpoise in the bottom set gillnet fishery in the Estuary and Gulf of St Lawrence using information obtained from an At-sea observer program.

Year	Data source	Targeted species	Zones	N of by-catch per haul (n observed hauls)	N commercial hauls	Estimated takes	C.V. (%)	95% CI
2001	Observers	Atlantic cod	North-western Gulf	^a	9	^a	^a	^a
			North Shore	^a	1428	^a	^a	
			4R	0.0143 (70)	8814	126	99	0–378
			Miscou	0 (362)	3887	0		
			Southern Gulf	0.04478 (67)	1116	50	53	0–100
		Greenland halibut	North-western Gulf	0 (190)	2686	0	-	-
			North Shore	^a	475	^a	^a	^a
			4R	0 (16)	4716	0	-	-
			Miscou	^a	61	^a	^a	^a
			Southern Gulf	-	0	-	-	-
2002	Observers	Atlantic cod	North-western Gulf	^a	60	^a	^a	^a
			North Shore	0.05882 (17)	2529	149	98	0–446
			4R	0 (80)	9404	0	-	-
			Miscou	0.0086 (232)	2522	22	74	0–54
			Southern Gulf	0 (48)	139	0	-	-
		Greenland halibut	North-western Gulf	0.0064 (468)	2835	18	57	0–42
			North Shore	^a	328	^a	^a	^a
			4R	0 (19)	4047	0	-	-
			Miscou	^a	31	^a	^a	^a
			Southern Gulf	-	0	-	-	-

^aAt-sea Observer coverage too low to estimate harbour porpoise by-catch rates

Table 5. By-catch rates and total numbers of harbour porpoise by-catches in the bottom-set Sentinel gillnet fishery of the Estuary and Gulf of St Lawrence in 2001 and 2002

Year	Data source	Targeted species	Zones	N of by-catch per haul (n hauls)	Total n of by-catches
2001	Sentinels	Atlantic cod	North-western Gulf	0 (22)	0
			North Shore	0.04824 (539)	26
			4R	0.02148 (512)	11
			Miscou	0.23590 (195)	46
			Southern Gulf	0.22222 (135)	3
			Total:		86
2002	Sentinels	Atlantic cod	North-western Gulf	0 (12)	0
			North Shore	0.03063 (457)	14
			4R	0.03226 (403)	13
			Miscou	0.15198 (329)	50
			Southern Gulf	0 (233)	0
			Total:		77

Table 6. Comparisons 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.

Parameter	Sentinels (N = 51)	Observers (N = 188)	$F_{\text{Anova on ranks}}$	Pr > F
	Median (P10-P90)	Median (P10-P90)		
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
Net length (m)	455 (455-455)	455 (455-455)	0.2	0.646

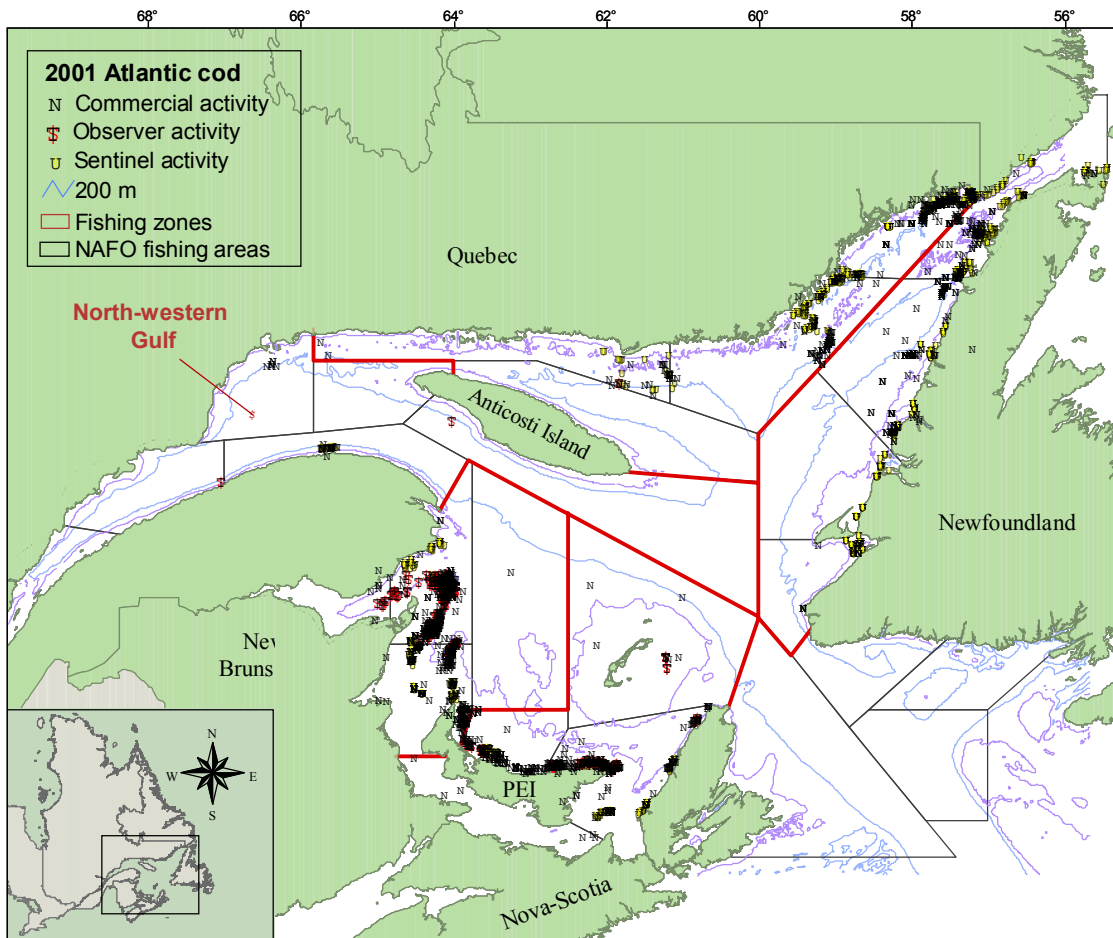


Figure 1. Partial distribution of Atlantic cod fishing activities using bottom set gillnets in 2001. Information on fishing location was unavailable for most fishing activities from the NAFO Area 4R, and a large fraction of the commercial fishery activities from Areas 4S and 4T.

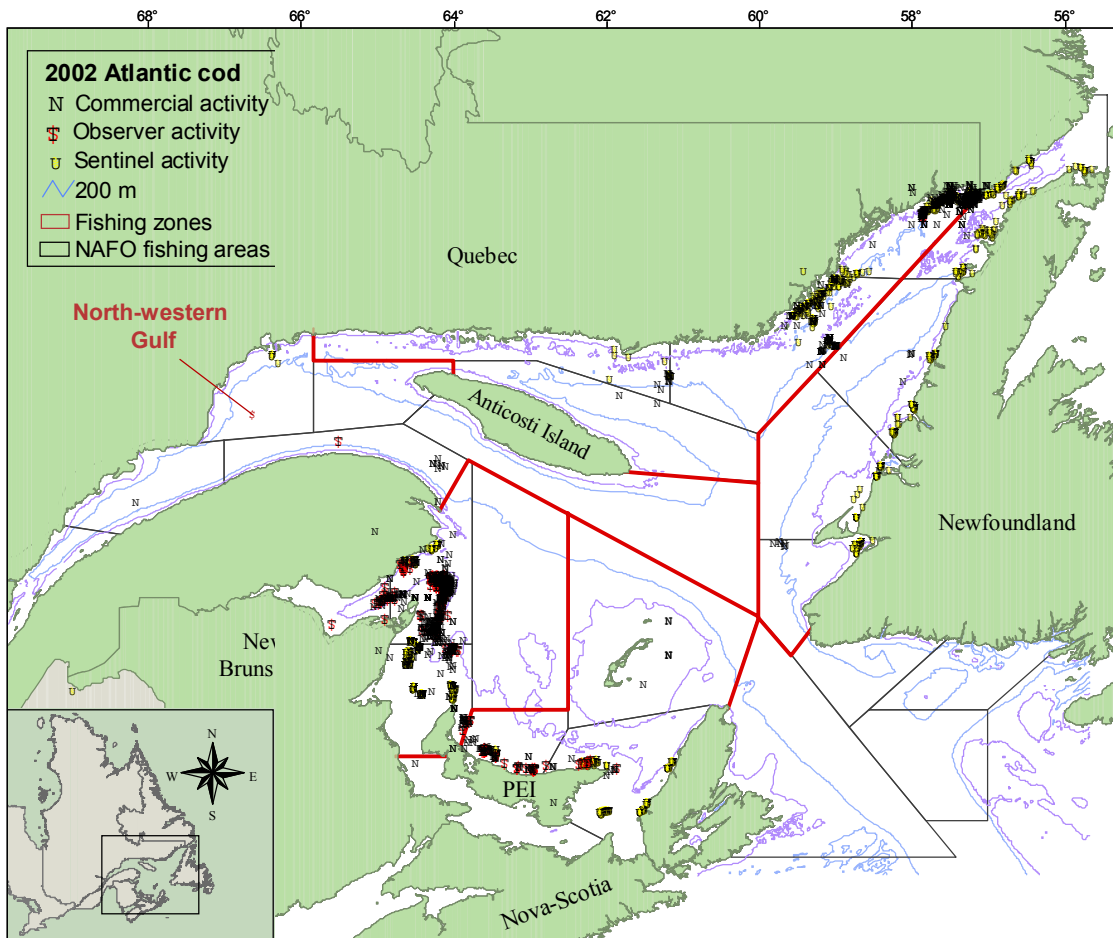


Figure 2. Partial distribution of Atlantic cod fishing activities using bottom set gillnets in 2002. Information on fishing location was unavailable for most fishing activities from the NAFO Area 4R, and a large fraction of the commercial fishery activities from Areas 4S and 4T.

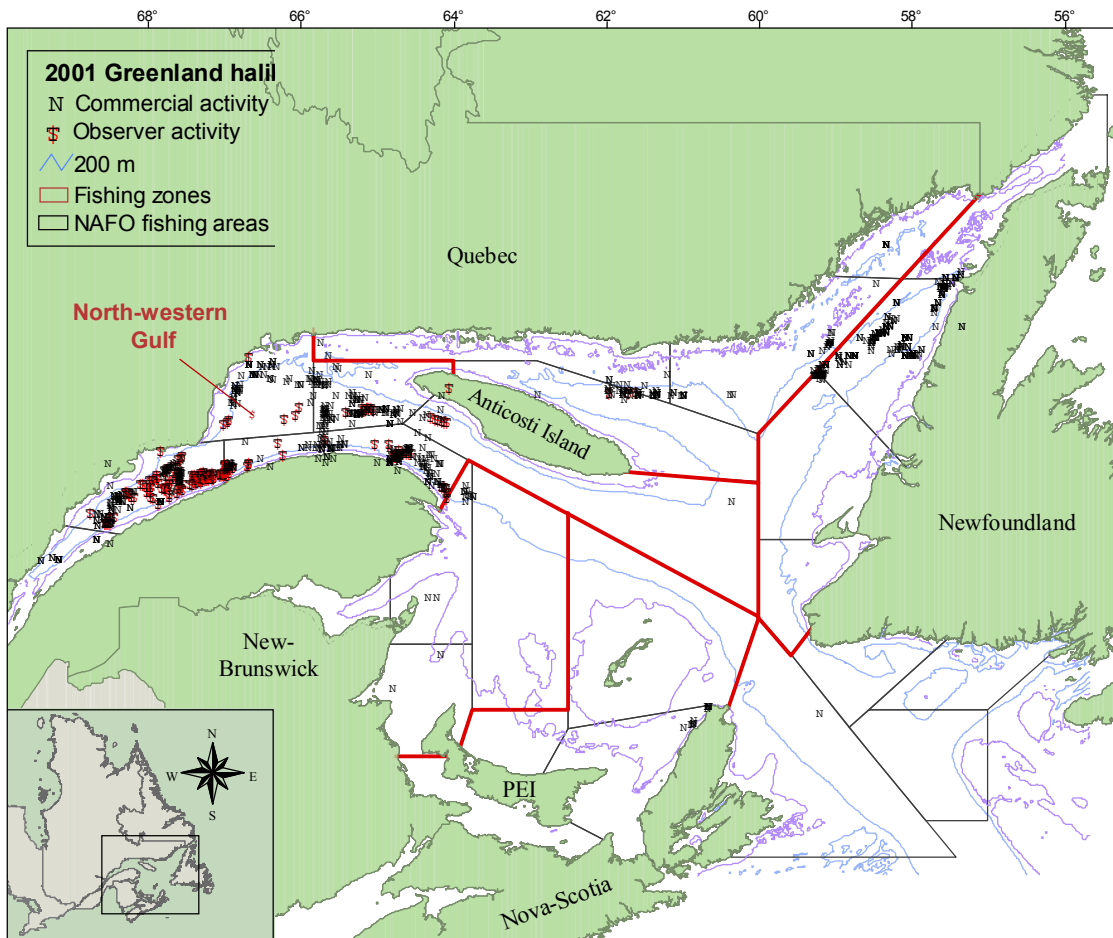


Figure 3. Partial distribution of Greenland halibut fishing activities using bottom set gillnets in 2001. Information on fishing location was unavailable for most fishing activities from the NAFO Area 4R, and a large fraction of the commercial fishery activities from Areas 4S and 4T.

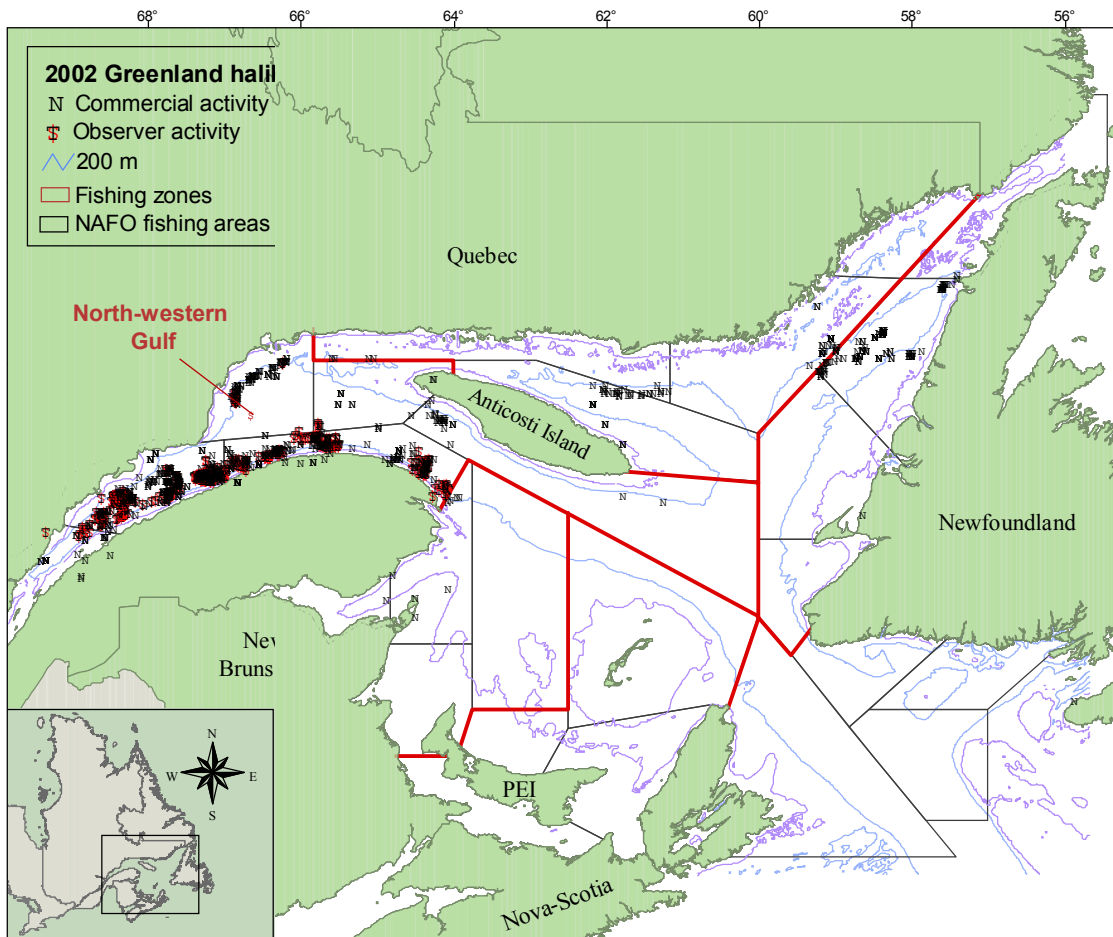


Figure 4. Partial distribution of Greenland halibut fishing activities using bottom set gillnets in 2002. Information on fishing location was unavailable for most fishing activities from the NAFO Area 4R, and a large fraction of the commercial fishery activities from Areas 4S and 4T.

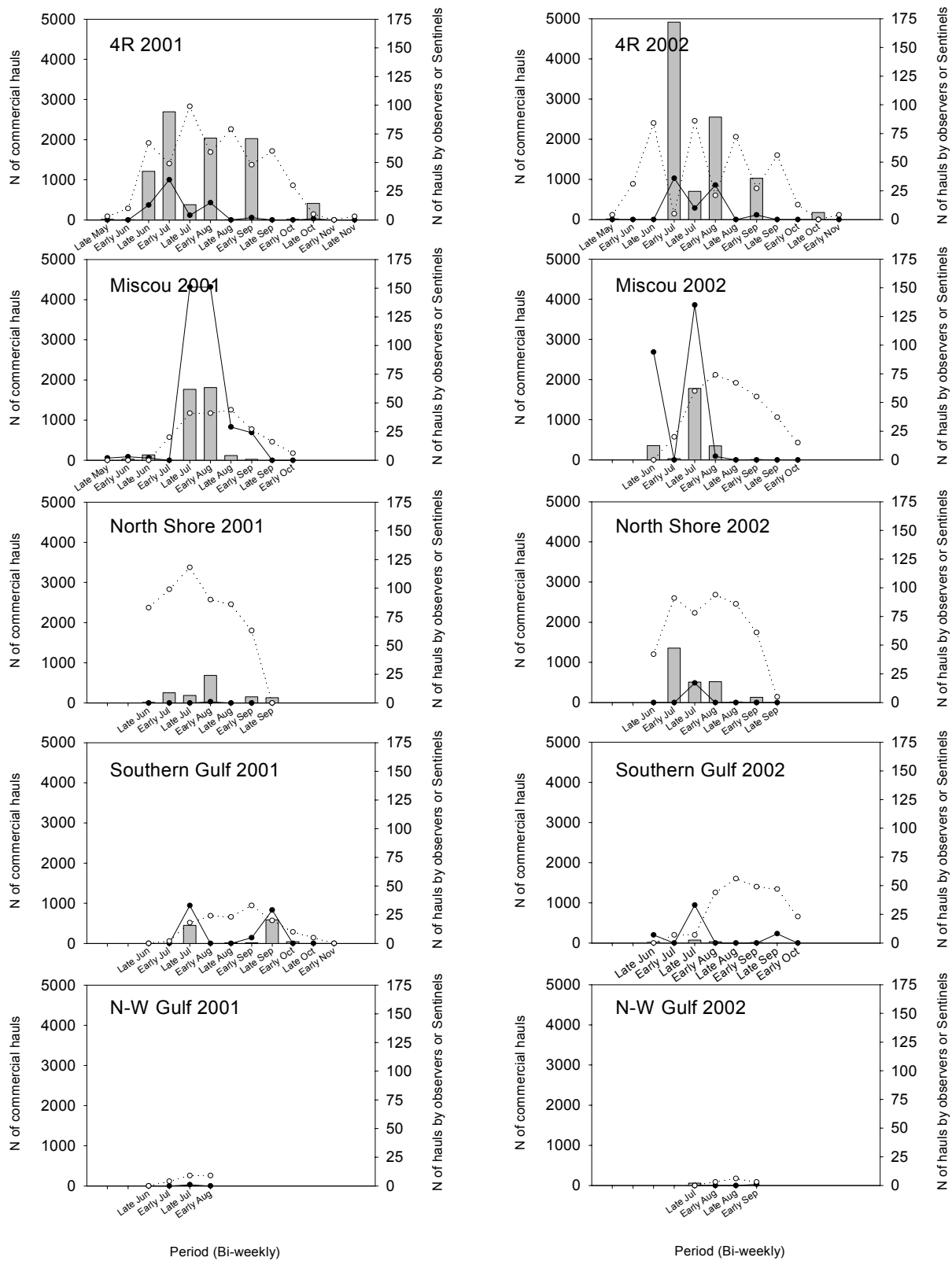


Figure 5. Seasonal distribution and intensity of commercial fishing activities (bars), At-sea Observer activities (plain line), and Sentinel fisheries (dotted line) for Atlantic cod in five zones of the Estuary and Gulf of St Lawrence in 2001 and 2002.

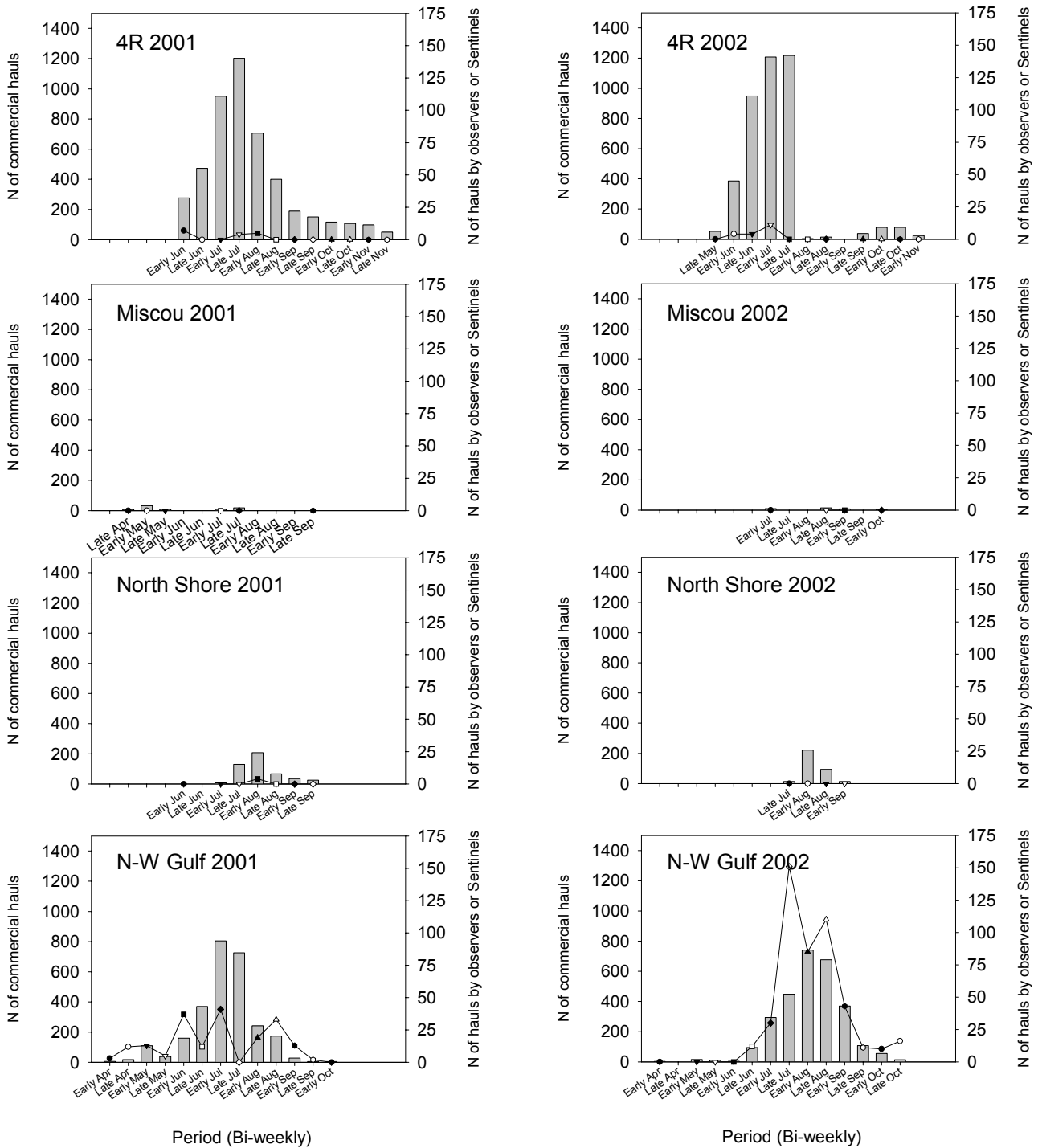


Figure 6. Seasonal distribution and intensity of commercial fishing activities (bars), and At-sea Observer activities (plain line) for Greenland halibut in the four zones of the Estuary and Gulf of St Lawrence where some fishing activity occurred during 2001 and 2002.

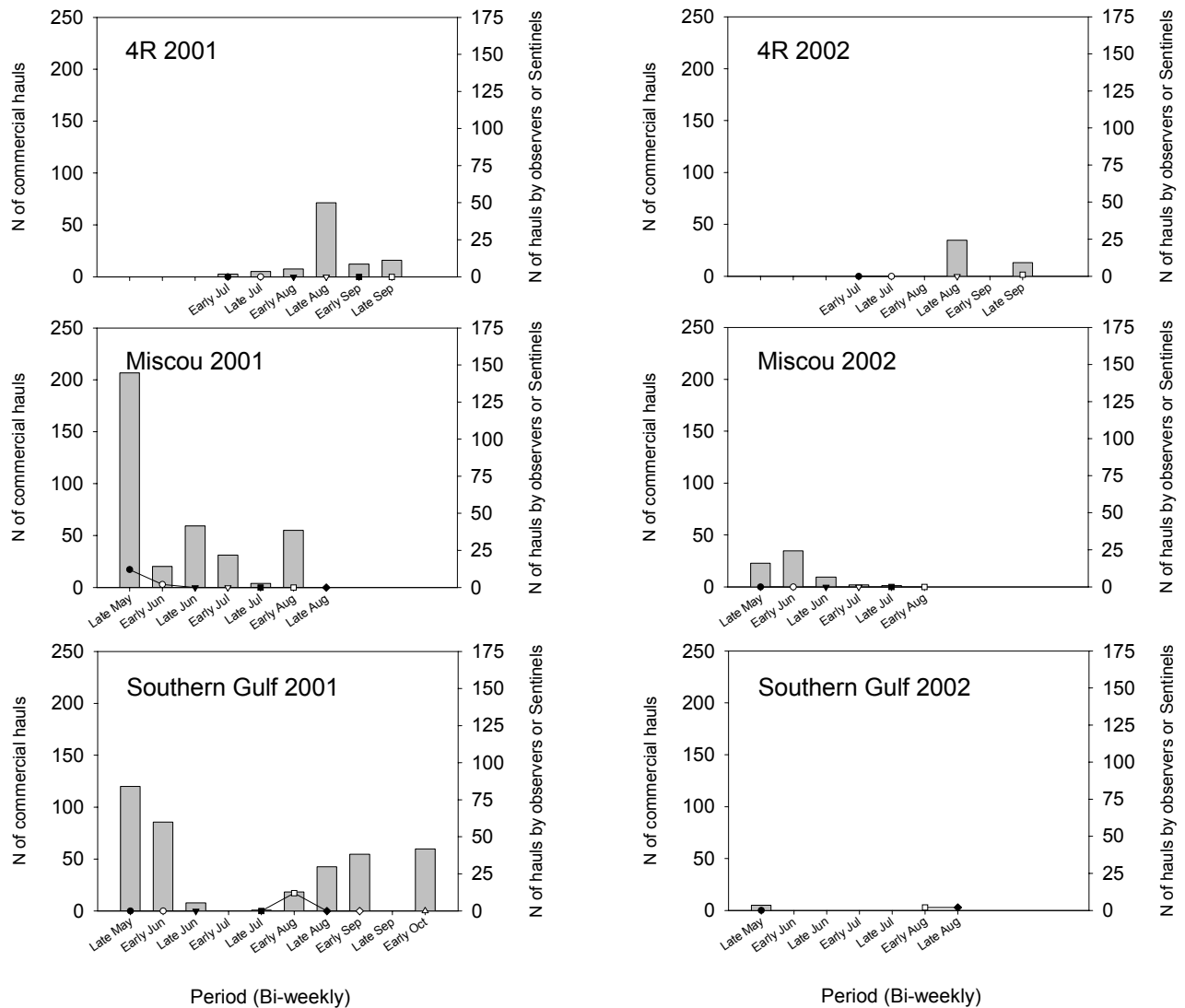


Figure 7. Seasonal distribution and intensity of commercial fishing activities (bars), and At-sea Observer activities (plain line) for winter flounder in the three zones of the Estuary and Gulf of St Lawrence where some fishing activity occurred during 2001 and 2002.

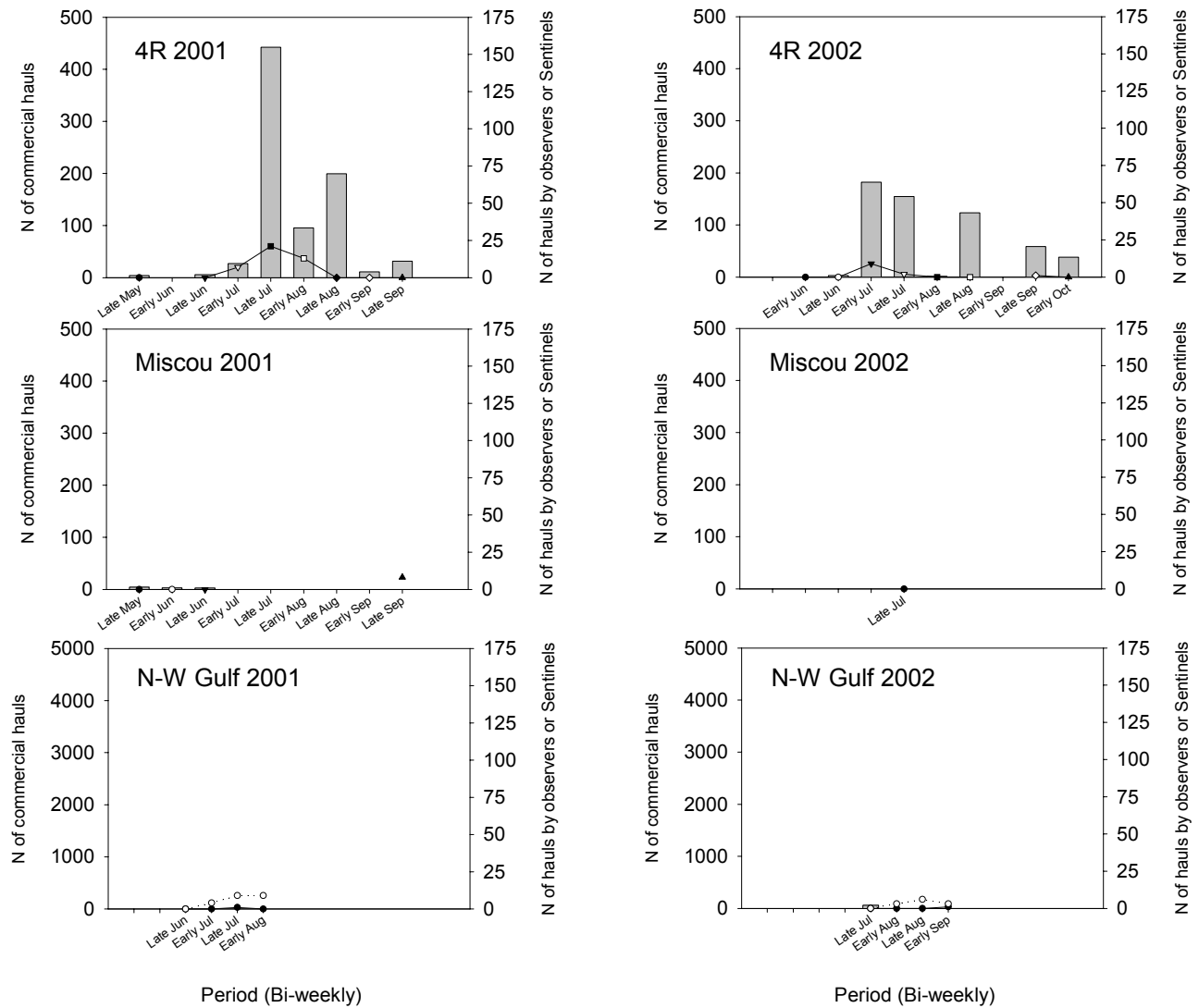


Figure 8. Seasonal distribution and intensity of commercial fishing activities (bars), and At-sea Observer activities (plain line) for American plaice in the three zones of the Estuary and Gulf of St Lawrence where some fishing activity occurred during 2001 and 2002.

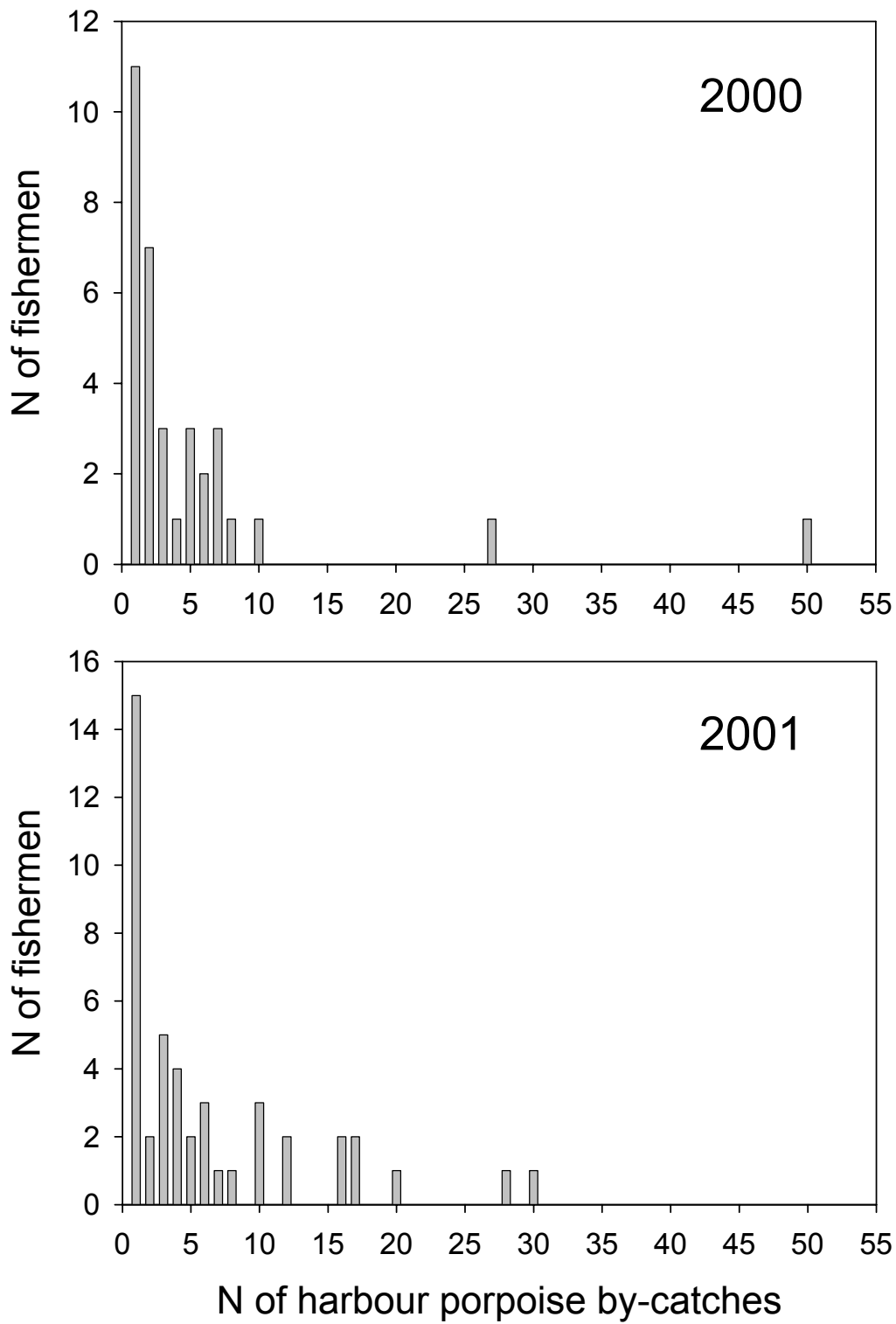


Figure 9. Frequency distribution of the number of harbour porpoise by-catches per gillnet fisherman in the Estuary and Gulf of St Lawrence in 2000 (n = 34) and 2001 (n = 45).

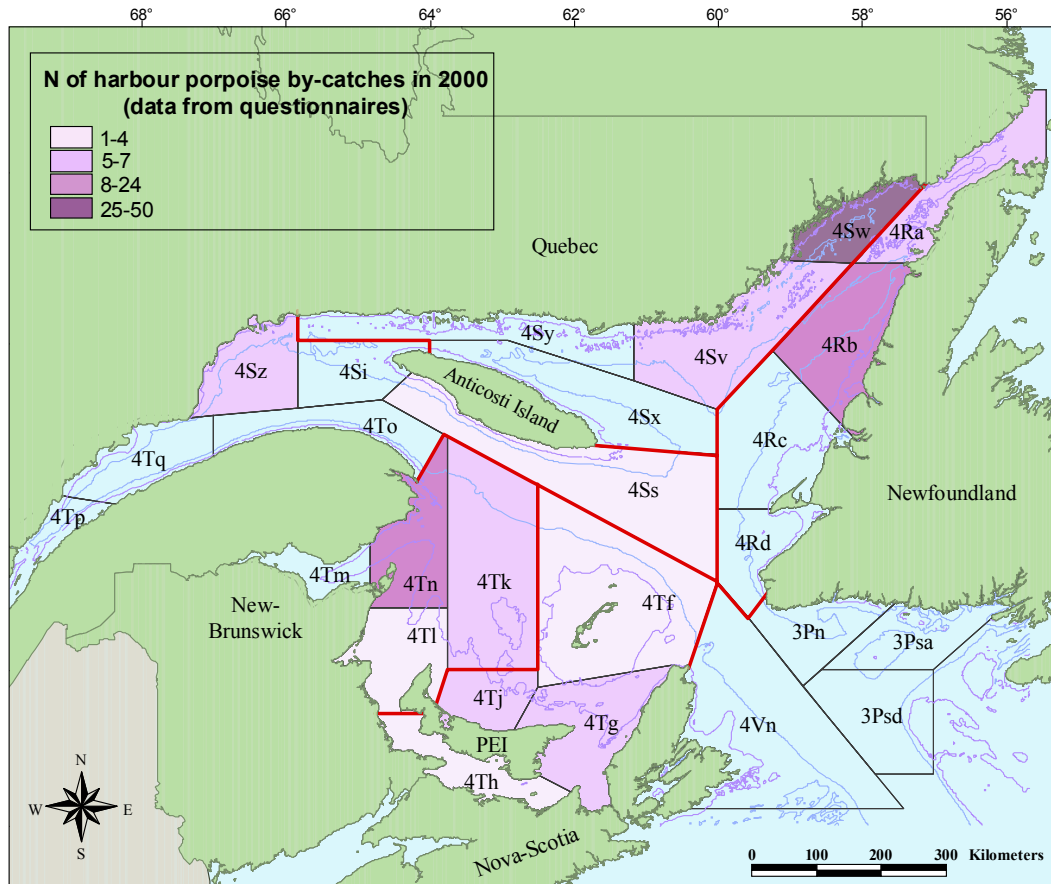


Figure 10. Distribution of 181 harbour porpoises incidentally taken in the gillnet fishery in 2000, as indicated by questionnaires sent to a sample of fishermen active during the 2000 fishing season. Forty-five harbour porpoises were taken in undetermined location.

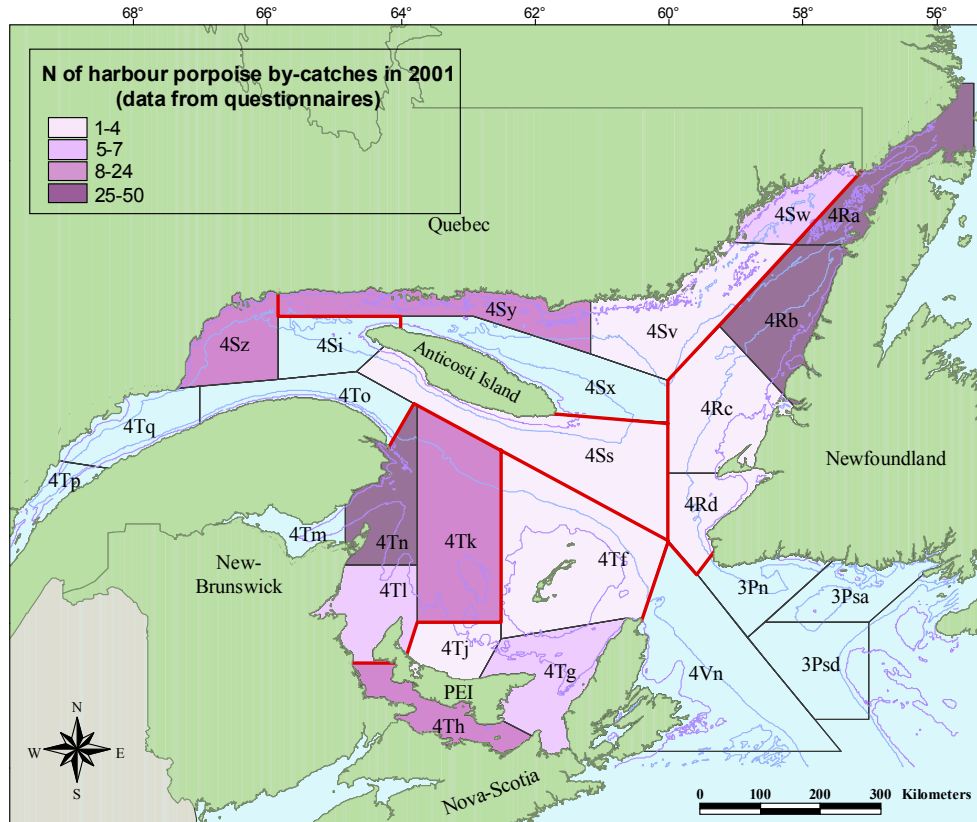


Figure 11. Distribution of 291 harbour porpoises incidentally taken in the gillnet fishery in 2001, as indicated by questionnaires sent to a sample of fishermen active during the 2001 fishing season. Forty-nine harbour porpoises were taken in undetermined location.

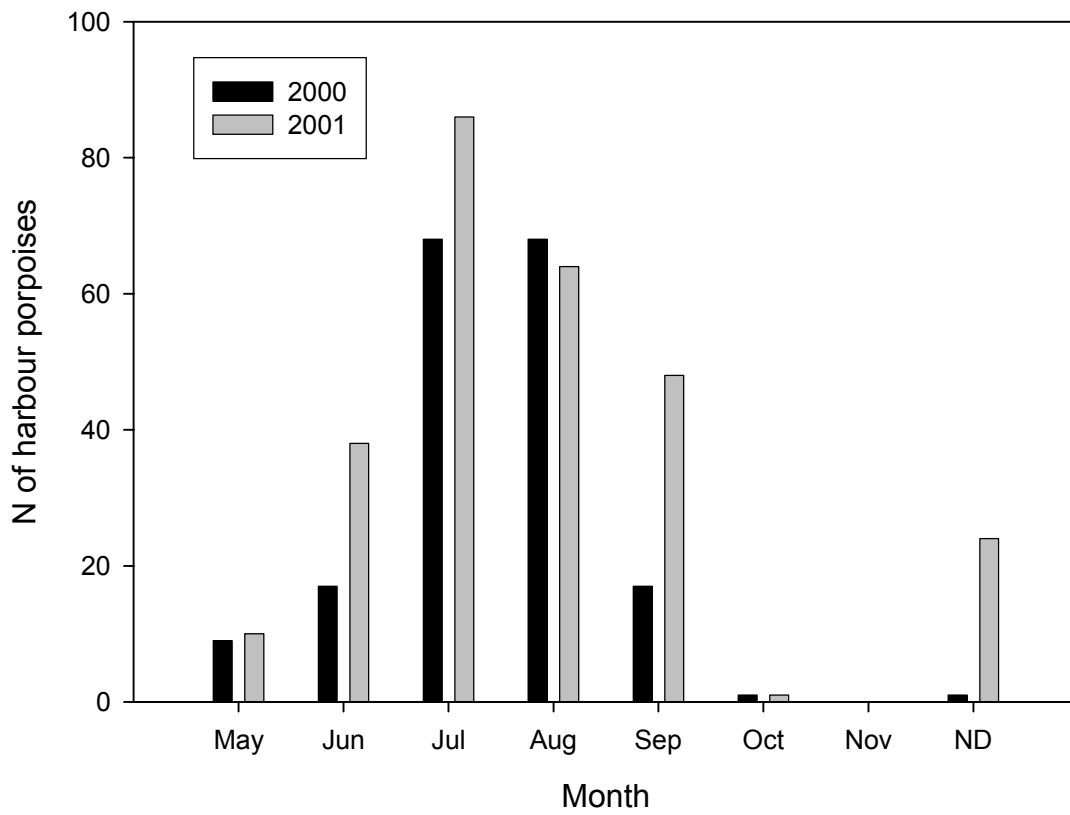


Figure 12. Monthly distribution of incidental takes of harbour porpoises in 2000 and 2001, as indicated by questionnaires to gillnet fishermen.

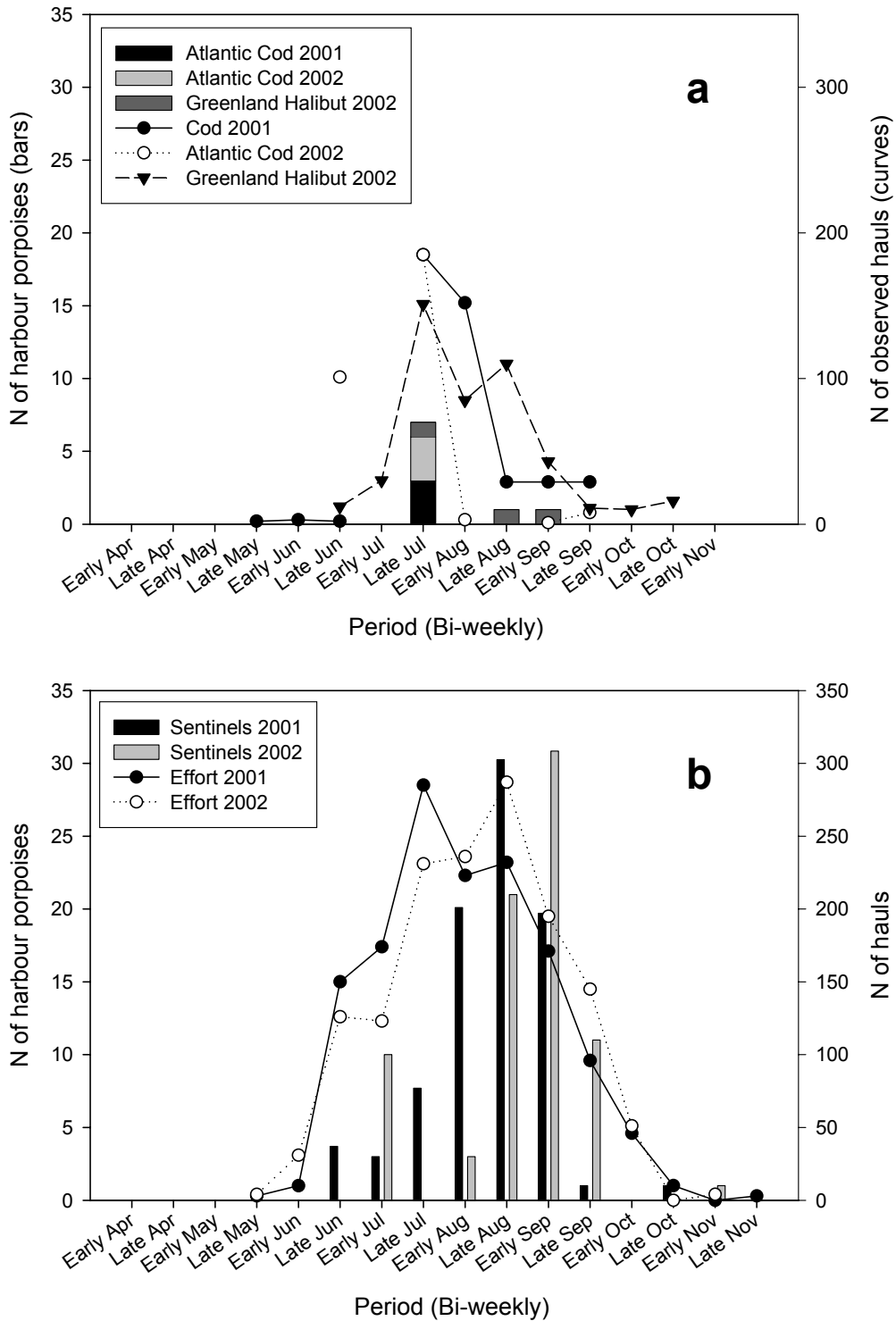


Figure 13. Monthly distribution of activities (curves) by a) At-sea observers and b) Sentinel fisheries, and incidental takes reported by these two groups (bars) in 2000 and 2001.

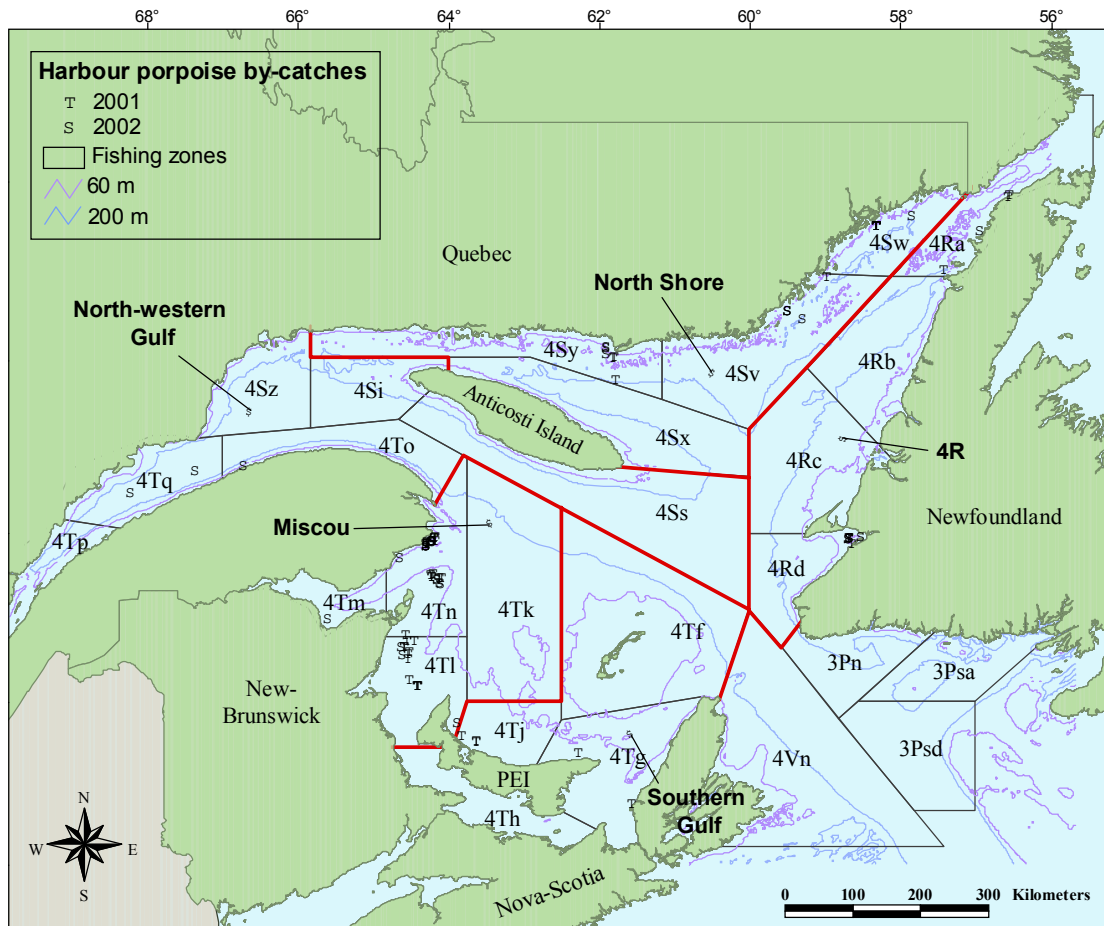


Figure 14. Spatial distribution of harbour porpoise by-catches reported in 2001 and 2002 by At-sea Observers and Sentinel fisheries.

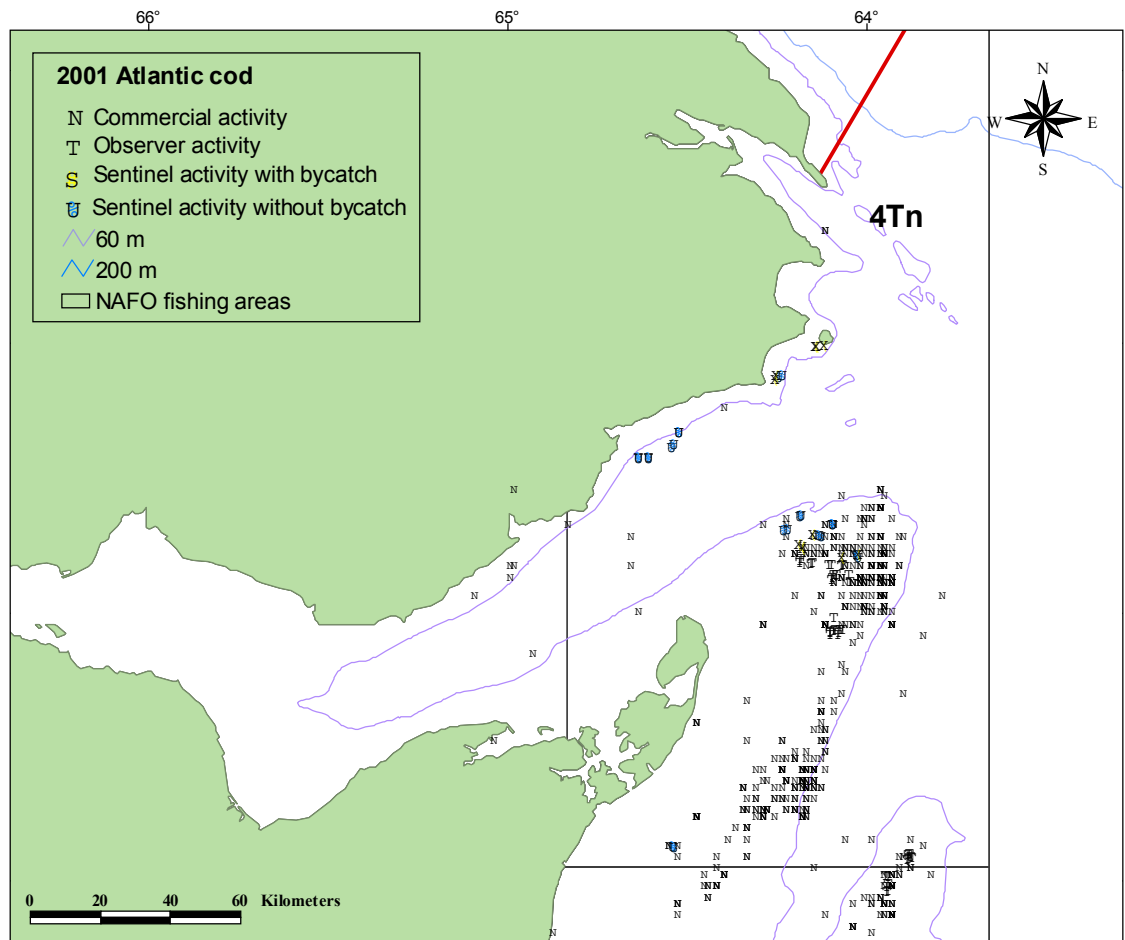


Figure 15. Spatial distribution of commercial cod fishery activities with and without At-sea observers on board, and of Sentinel fisheries that did or did not report by-catches of harbour porpoises. Fishing activities illustrated on this figure all took place in August and early September 2001 in NAFO Area 4Tn.

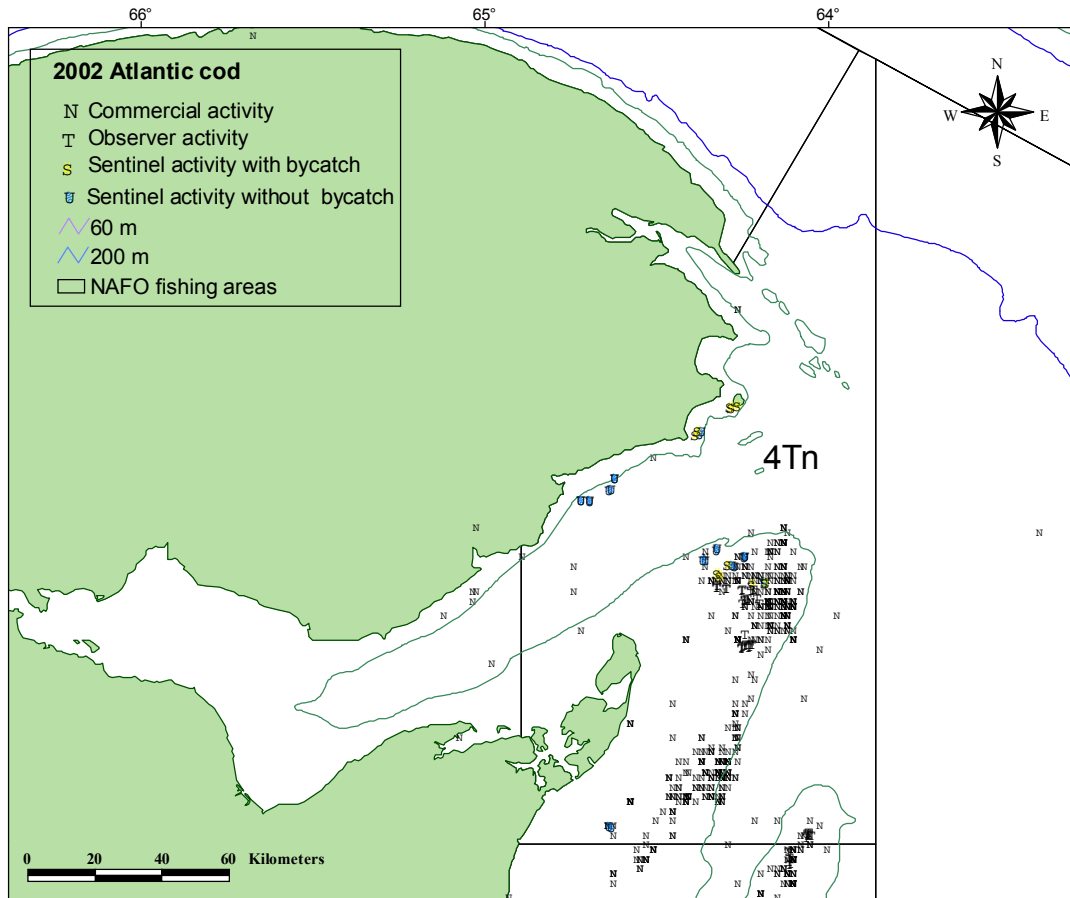


Figure 16. Spatial distribution of commercial cod fishery activities with and without At-sea observers on board, and of Sentinel fisheries that did or did not report by-catches of harbour porpoises. At-sea observer activities presented in this figure occurred between late July and early August, and did not overlap temporally with activities by Sentinel Fisheries, which occurred in late August and September in 2002.