Interaction between sperm whales (*Physeter macrocephalus)* and northern bottlenose whales *(Hyperoodon ampullatus*) with deep-water trawlers in the western North Atlantic

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Abstract

This paper describes the behavioural ecology of two whale species: sperm whales (*Physeter macrocephalus)* and northern bottlenose whales (*Hyperoodon ampullatus)* interacting with benthic trawlers fishing off the eastern Grand Banks of the western North Atlantic. Whale behaviors were observed and compared in the course of four phases of fishing activities. Sperm whales and northern bottlenose whales were more likely to be observed during hauling. During this phase individuals of both species were observed engaging in probable feeding behavior close to the surface, suggesting that whales preyed on fish escaping from the net. Photo identification distinguished 10 unique sperm whales and resights indicated that some individuals had probably followed trawlers through several sets, over distances up to 234 km. By contrast, there were no resights of northern bottlenose whales within this study or with individuals from photo-identification catalogues for the endangered Scotian Shelf population or the Arctic population. The population designation of northern bottlenose whales in this study and the connection between two currently recognized subpopulations is unknown.

1. Introduction

Over the last two decades, commercial fisheries have increased in all the world's oceans with diverse unintended impacts on marine ecosystems. Interactions between marine mammals and fisheries have been recognized as a major conservation issue and the occurrence of cetacean bycatch, entanglement and depredation of fisheries has been reported worldwide (Davidson et al. 2012; Northridge and Hofman 1999; Read 2008; Read et al. 2006). Fisheries can also indirectly threaten cetaceans when overexploitation, decreasing their prey availability (Carlucci et al. 2021). However, feeding in association with fishing activities may provide short term energetic benefits for cetaceans by increasing the quantity and the quality of the prey consumed, while reducing foraging costs and providing some foraging advantage (Amelot et al. 2022; Fertl and Leatherwood 1997; Silva et al. 2002).

Bottom trawling accounts for 20% of global fisheries (Hiddink et al. 2017), and interactions have been observed with a range of both odontocete and mysticete species of whale (Barros et al. 2004; Bearzi et al. 2003; Bonizzoni et al. 2022; Chilvers and Corkeron 2001; Couperus 1997; Fertl and Leatherwood 1997; Hucke-Gaete et al. 2004; Kovacs et al. 2017; Leatherwood et al. 1989; Lien 1994; Morizur et al. 1999). In the western North Atlantic, the offshore habitat and diets of deep diving sperm whales (*Physeter macrocephalus*) and northern bottlenose whales (*Hyperoodon ampullatus)* are known to overlap with areas and species targeted by trawlers (Clarke et al. 1993; Gaskin and Cawthorn 1967; Gowans et al. 2000; Karpouzli and Leaper 2004; Northridge 1984; Wimmer and Whitehead 2004). While some populations have been the subject of long-term research (e.g., Scotian Shelf population, Hooker et al. 2019), the inaccessibility of their remote pelagic habitat has limited opportunities for ongoing studies and monitoring, particularly compared to coastal cetacean species (Hooker 2015; Hooker et al. 2001; Hooker et al. 2019).

Interactions between trawl fisheries and one or both of these species have been reported from several areas of the western North Atlantic, (Karpouzli & Leaper, 2004, reported interactions involving sperm whales in fisheries off Newfoundland since at least 1996). In Arctic waters (in central Baffin Bay, Nunavut, Canada), interactions involving both sperm and northern bottlenose whales have been observed since at least 2005 (Johnson et al. 2020) while (Fertl and Leatherwood 1997) document northern bottlenose whales interacting with trawlers on the Scotian shelf as early as 1997. The Scotian Shelf population of Northern Bottlenose whales is listed as Endangered, under Canada's *Species At Risk Act.* Research on the risks of fisheries

to this species and development of mitigation measures where necessary, has been identified as a priority (Fisheries and Oceans Canada, 2016). Responsible ecosystem-based fisheries management requires detailed knowledge of whale interactions, real and perceived impacts on fisheries and whales, and any long-term trends in these interactions.

Studies of human-wildlife interactions continue to shed new light on how animal behavior develops and spreads through learning. In describing interactions between two species of deep diving whales (i.e., sperm whales, northern bottlenose whales), and benthic trawlers, the objectives of this paper are: (1) to document the earliest detailed observations of northern bottlenose whales interacting with trawl fishers off the Grand Banks in the western North Atlantic; and (2) contribute to a broader understanding of the ongoing and expanding prevalence of sperm whales engaging in fishery interaction behavior. This study provides an important baseline for fishery and cetacean management by documenting the history of these interactions in the region, as well as data on factors involved in whale-trawl association behavior.

2. Material and Methods

2.1 Study area

The study area is managed under the provisions of the Northwest Atlantic Fisheries Organization (NAFO), which requires vessels to carry a fisheries observer on board. Data were collected between the 20th of July and the 13th of September (50 days) in 2007, by UO while working as a NAFO observer on the 51 m stern trawler *Playa Menduiña Dos*. During this time, the vessel operated in four NAFO divisions: 3L, 3M, 3N and 3O (**Figure 1**). Fishermen had vernacular names for their preferred fishing areas, where they typically target different species. The location of these areas within the NAFO blocks are also shown in **Figure 1**. Fishing effort in each area was decided by the skipper. Trawl tows were typically made parallel to depth contours. The duration of each haul depended on factors such as the nature of the sea bottom (depth and relief) and varied between fishing areas.

2.2 Cetacean Monitoring and Behavioral sampling

Cetacean monitoring was carried out opportunistically, typically from the bridge of the vessel and at times outside the observer's scheduled duties. During each whale observation period (~30 mins), dedicated scan sampling for whales occurred every ten minutes. Each scan was

complete within one type of vessel activity. Whale encounters started when whales were observed at the surface and ended when 10 minutes had elapsed without whales. The distance between the vessel and the net varied depending on the fishing area and depth (**Table S1**). Vessel activity states included: (1) preparing and shooting the net, (2) towing, (3) hauling and (4) navigating to other fishing areas. Information recorded during each observation period included the vessel location, vessel speed, fishing activity, cloud cover, sea state, and visibility. Data on cetacean encounters included species, behavior, and group size. When possible, photographs were taken of the dorsal fin and the surrounding flank area of both species and of the flukes of sperm whales using a digital camera (Canon EOS 30) with a 200 mm lens.

Six different whale behaviors were scored when whales were within 5-300m of the vessel and observation conditions were good (<= Beaufort 3): (1) swimming parallel and alongside the vessel; (2) following the vessel at a constant speed and near constant distance astern (**Figure 2**); (3) swimming in an opposite direction to that of the vessel; (4) fluke up; (5) probable feeding; and (6) breaching. Times of surface behaviors from whales, such as dives with fluke up, lob-tailing or breaching were also noted.

Probable feeding behavior could only be easily observed when animals were astern of the vessel, during the final stage of hauling when the cod end was close to the vessel's stern and fish could be seen escaping the net. Probable feeding behavior was inferred differently for sperm and northern bottlenose whales. Sperm whales would slowly turn sideways or upside down just below the surface, showing first the dorsal fin, then the blowhole, and finally, their whitish jaw (**Figure 3**). In contrast, bottlenose whales would make repeated short shallow dives, as they surfaced their beak was frequently visible (**Figure 4C-D**). Sea birds were also observed feeding on escaping fish at the same time (e.g., great shearwaters; *Ardenna gravis,* northern fulmars; *Fulmarus glacialis*).

2.3 Photo-identification analysis

Data collection opportunities were more constrained than for studies using dedicated platforms (Arnbom 1987; Childerhouse et al. 1995; Gowans and Whitehead 2001; Hammond et al. 1990; Whitehead 1990; Whitehead and Gordon 1986), photographs could only be taken when whales came close the boat and this was more likely during certain phases of fishing. Photographs were taken irrespective of the presence of any obvious marking on the individual, and efforts were made to obtain multiple photographs of every individual in each encounter. Because was

a short field study there was a low probability that marks would change during it and marks that could be seen anywhere on an individual's body (i.e., backs, dorsal fins, melons, flukes), were considered persistent and reliable for identification (e.g., notches, linear scrapes, patches). Initially, separate catalogue were established for flank fin markings observed and the left and right side of the body as per (Feyrer 2020; Gowans and Whitehead 2001). However, it was often possible to link these when images from the left and rights side and/or flukes could be reliably assigned to the same individual.

2.4 Statistical analysis

Encounter rates were calculated by dividing the number of encounters by the length of each observation period. Average encounter rates were for vessel activity state in each area. To assess the effect of different fishing areas, vessel activities and the interaction between vessel activity and fishing area on whale presence we modelled relationships between these parameters, sighting conditions (i.e., sea state (Beaufort), visibility (m), and cloud cover (%) and daylight), and whale observations (presence and absence) using binomial generalized linear models (GLMs) with an offset for effort (observation time). Models for sperm whales and northern bottlenose whales were built separately. Observations made in fishing areas with < 10 observation periods and while the vessel was travelling, were excluded to avoid model separation due to singularities. The fluke-up rates of sperm whales were compared for each vessel activity using Kruskal Wallis and Tukey test. All statistics were completed in R (2019)(R Core Team 2018).

3. Results

3.1 Vessel activities

Overall, 200 hours of different fishing activities were monitored over 50 days, with 8.3 hours of observation occurring at night (between 21:30 and 6:30). A total of 248 observational periods were completed in seven different fishing areas and while travelling between sites (**Figure 5A-B**). Observations were made during all types of fishing activity and the total hours of observation, vessel speed and whale behavior during each fishing activity is summarized in **Table 1**. A total of 128 net deployments were monitored. Summaries of the hauls monitored in each fishing area (i.e., number, average duration, observational effort, net distance and depth, total days and target species) in are shown in **Table S1**.

3.2 Whale encounters

Four cetacean species were observed: sperm whales, northern bottlenose whales, common dolphins and long-finned pilot whales. The most frequently encountered species were sperm whales (N=129 encounters across 81 observation periods) and northern bottlenose whales (N=86). The two species were seen together on 34 occasions. Whale behavior was also observed at night, when whales were close (10-30 m) to the boat. Nighttime observations relied on the vessel's lights, which were mainly directed astern to allow the codend to be monitored as the net was hauled to the surface. Observations were made during 14 nighttime net hauls, including four encounters with sperm whales and six encounters with northern bottlenose whales. Whale behaviour at nighttime was similar to that observed during the day. Other cetaceans observed included common dolphins which often rode the bow the fishing vessel. Long-finned pilot whales were often sighted but were not observed to interact with the boat or fishing gear.

Regional differences and whale encounters

Locations of encounters for each species are shown in **Figure 5**. Northern bottlenose whales and sperm whales were sighted in fishing areas: *La Décima* (3L), *Playa Nova* (3L), *Carson Canyon* (3N) and *O Pequeno* (3N), northern bottlenose whales were also sighted in *Raíz Cuadrada* (3O). These areas are generally on or close to the slope edge, where depths are between 700-1450. Greenland halibut was the target in these areas. Neither species was sighted in *Flemish Cap* (3M) nor *El Seco* (3N), where fishery targets were redfish and thorny skates respectively and water depths were much shallower 50-90m (*El Seco*), and 50-800m *(Flemish Cap*).

The mean encounter rates for sperm whales and northern bottlenose whales in each area are summarized in **Table 2** and **Figure 6C-D.** *La Décima* had the highest mean encounter rate of 1.08 sperm whales per hour of observation and the maximum number of sperm whales during an encounter (6 individuals) was observed in *Playa Nova*. Over all sites, the mean number of sperm whales sighted during an encounter was 1.5 (**Table 2**). For northern bottlenose whales, encounter rate was highest in *O Pequeno* with 0.78 encounters per hour of observation. The maximum number of individual northern bottlenose whales in an encounter was 9, in *La Décima*, and the mean number of individuals during all encounters was 2.3 (**Table 2**).

Whale behaviors and encounters during different vessel activity states

The behavior of both sperm and northern bottlenose whales differed with vessel activity, particularly between towing and hauling. During towing most sperm whales were observed swimming parallel to and either abeam or astern of the vessel maintaining a constant speed and distance. The longest sighting of a sperm whale, one hour and 25 minutes of continuous observation, occurred during towing. Possible feeding behavior was never observed during towing but lobtailing (energetic tail slaps at the surface) and repeated breaching was observed on one occasion. Northern bottlenose whales disappeared soon after shooting but were typically observed swimming about as far behind the vessel as the net was being towed during the early towing phase. On two occasions repeated breaching was observed (**Figure 4A-B**).

During the net hauling phase the boat slows down and the net winches on deck generate an intense noise and vibration in the hull. At this time, both sperm whales and northern bottlenose whales were often observed astern, swimming quickly towards the vessel. After hauling, and during preparing/shooting no feeding behavior on discards was observed.

Sperm whale "fluke ups" were observed some five times more often during hauling than during preparing/shooting, and almost 2.5 times more often towards the end of hauling than during towing (Kruskal-Wallis test, Tukey HSD $p<0.05$, N=248). The fluking rate per whale per hour was significantly higher during hauling (0.5 flukes) than during preparing/shooting and towing (0.1 and 0.2 flukes, respectively) (Kruskal-Wallis test, Tukey HSD $p<0.05$, N=248) (**Table 1**). Sperm whales typically fluke up before steep dives, a behaviour that suggests whales might be diving down to feed on fish as the net is being hauled in. Other probable feeding behavior was only observed at the end of hauling, once the codend was close to the surface, coinciding with birds feeding on escaping fish at shallow depths. Fluke ups were not observed at this time.

The mean encounter rates for sperm whales and northern bottlenose whales observed during each vessel activity state is summarized in **Table 2 and Figure 6C-D**. Encounter rates for both sperm whales and northern bottlenose whales was highest during hauling (**Figure 6C**). Navigating to other fishing areas had the lowest encounter rate for sperm whales, whereas the lowest encounter rates for northern bottlenose whales occurred during towing (**Figure 6C)**.

Whale encounter modelling

Fishing area and vessel activity state were both significant terms in modelling northern bottlenose whales and sperm whale presence. Sighting condition variables were also significant to the detection of both species; however sperm whales were affected by different variables (i.e., Sea State, Visibility, Daylight), than northern bottlenose whales (i.e., Cloud Cover, Daylight). GLMs with these variables had significantly more support than models with additional or fewer terms (Table S2). Inspection of coefficients indicated that *Decima* and *Playa Nova* were significant areas ($p<0.05$) relative to *Flemish Cap* for both sperm whale and northern bottlenose whale presence. Two areas, *Raiz Cuadra* and *Divisoria,* were not included in the models due to low observation effort (**Table 1**). *El Seco*, where no whales were observed is not significant, despite a large number (n =26) observations. This is likely due to absences inflating estimates and standard error. All vessel activities were significant for whale presence. Towing (T), Hauling (H) and Preparing or Shooting the Net (P/S) were both positively associated with sperm and northern bottlenose whale presence (Table S2). Navigating (N) between areas was not included in GLMs as there was no region associated with the activity.

3.3 Photo identification

Some seven thousand photographs were taken during whale encounters and individuals were identified using distinctive markings. Twenty-three northern bottlenose whale identifications were made on 50 separate days based on photographs of the right-side dorsal fins (15 other individuals were identified from left-side dorsal fin). None of the northern bottlenose whales identified were seen in consecutive hauls or on more than one day (**Figure 7**).

A maximum of ten to a minimum of six sperm whale identifications were made using distinctive marks on various parts of their bodies and flukes **(Figure 7 and Table S3**). Three whales were only identifiable from marks on one side of their bodies, four IDs had marks that could be seen on both sides of their bodies. Two IDs were based only on the tail fluke. **(Table S3)**.

Some individual whales demonstrated short-term site fidelity. *Scratchy* was seen on two occasions, 11 days apart, with a distance between encounters of only 4 km. *Neboa* was encountered eight times in a week while fishing in *Playa Nova,* across more than 100 km (**Table S3**, **Figure S2).** The calculated minimum average swim speed for *Neboa* over this period was 4.0 km/h. *Sparrow* was observed repeatedly with only 5-16 km between encounters,

but then seen again on two consecutive days, 58 km away. *Faneca* was encountered five times on three consecutive days in *Carson Canyon. Breixo*, one of the easiest whales to identify, was seen during five encounters in *Playa Nova* and subsequently 20 days later and 235 km away in *Carson Canyon*. This was the maximum distance between two sightings of a sperm whale identified in this study.

Associations between individuals were defined as distinct IDs sighted during the same unit of observation. There are no indications of preferred associations within this limited dataset, however we note that *Breixo* was seen with each of the other identified whales **(Fig. S1**)

Discussion

Here we document the earliest association between trawling activity and northern bottlenose whales in Newfoundland, an area located between two known population centers and provide additional details of behavioural interactions of individual sperm whales with fishers. This supports anecdotal observations made by fishermen prior to this study and cetacean researchers in the area in 2016-2017 (Marotte 2017). The fishing areas where sperm and northern bottlenose whales were most frequently encountered were targeting Greenland halibut, and these deep waters close to the continental shelf break have been characterized as preferred habitat for both whale species (Gomez et al. 2017; Whitehead and Wimmer 2005).

While we are unclear on their exact foraging strategy, whales appeared to increase their association with the vessel and engaged in probable feeding behavior during hauling. However, because the minimum codend mesh size for nets targeting Greenland halibut is 135mm (in these NAFO areas), it has been estimated that quite sizeable fish can escape this size net and become available as prey during towing. For Greenland halibut with a body length of 42cm, retention probability has been calculated as 0.5 and retention doesn't reach 100% until fish are ~55cm long (Huse et al. 1999). Open water may make it easier for whales to detect (i.e., either visually or acoustically) and catch escaping fish that may also be disoriented or disabled. The energetic costs of deep vs. shallow diving and differences in prey encounter rates compared to natural foraging may contribute to whales continuing and potentially increasing their associations with fishers in this and other areas (Amelot et al. 2022).

Sperm whales

Karpouzli & Leaper's (1997) earlier research on interactions between sperm whales and benthic trawlers in the same area as this study showed a pronounced difference in sighting rates with trawling phases. Their encounter rates were high during hauling (0.61) sightings per hour but they were very low during shooting and towing (~0.02). Here, sighting rates during hauling were similar to those of Karpouzli & Leaper (0.73 sightings per hour) but higher during shooting (0.78) and towing (0.63). This could suggest a possible growth in associative behavior by whales over time, given higher encounter rates when whales were observed to follow the net and boat through all fishing phases.

While encounters with whales appear higher during hauling, this could reflect a learned behaviour, or an observational bias of our study, as the whales are closer and easier to see from the vessel during this activity. However, hauling was also associated with a significantly higher fluke up rate; this distinct behavioural change, where the frequency of dives intensifies, also suggests an increase in opportunistic foraging during hauling. Although whales may also be preying on escapees during towing, there is the potential whales engage in multiple associative foraging strategies, which reflect the opportunities presented by the different phases of fishing.

Six of the photo-identified sperm whales were resighted during multiple encounters, even though conditions for photo-identification were far from ideal. This could indicate that these individuals followed the vessel through the different phases of trawling, in some cases over periods of several days. The maximum distance between two sightings of *Breixo*, 20 days apart, was 234 km. *Neboa* was seen during 8 hauls on three consecutive days, with sightings that were spread over more than 100 km. We cannot conclude whether these whales deliberately followed the vessel or moved between sites on his own accord. However, in the case of *Breixo*, it seems probable he moved independently as no sperm whales were observed during fishing activities that occurred between identifications. The average vessel speeds of fishing activities (e.g., 5.4 km/h shooting and towing, 1.44 km/h hauling), would allow the whales follow the vessel quite easily. Whitehead et al (1992) estimated sperm whales could travel 4.6 km/h, which aligns with the minimum speed whales would need to move between identification locations here (4.0 km/h).

Most sightings of sperm whales at higher latitudes are of single individuals, or more rarely small groups of males. Although sperm whale association with fisheries occurs in other areas,

outside of human influences coordinated behavior involving multiple male sperm whales has rarely been observed (Gordon et al. 1992). However, in a recent study, Kobayashi et al. (2020) described long term associations in male sperm whales in the North Pacific. They suggested that these groups may serve to enhance foraging success or provide protection against predators (Kobayashi et al. 2020). The mean cluster size of 1.6 observed in this study, is higher than observed during surveys of other areas of the Atlantic (e.g., 1.1 for Whitehead *et al.* 1992; 1.2 for Weir *et al.* 2001), and smaller than the cluster size of 2.2, found in a 2004 study of the same area by Karpouzli & Leaper (2004). The maximum cluster size of 6 sperm whales, observed during trawling in our study indicates male sperm whales are continuing to aggregate in larger groups in the presence of fishing vessels. Given the evidence of social learning increasing depredation and foraging associations with fisheries in other cetacean species, further study is needed to understand the mechanisms influencing this behaviour in sperm whales (Karpouzli and Leaper 2004; Kobayashi et al. 2020).

Northern bottlenose whales

In this study we document the first behavioural records of northern bottlenose whales associating with fisheries off Newfoundland. Although northern bottlenose whales are known to be curious and approach vessels (Feyrer et al. 2021), there are very few other reports of interactions between northern bottlenose whales and fishing vessels in the western North Atlantic, so it is difficult to know when and where this associating behaviour began. Karpouzli & Leaper's (1997) study on sperm whales, which took place from 1996-1997 in the same area, did not report any observations of northern bottlenose whales. However, in Fertl and Leatherwood's (1997) review of cetacean trawl interactions, they identified 15 records from the Scotian Shelf (identified in unpublished Fisheries and Oceans Canada data) in which northern bottlenose whales were reported to have "followed a trawl during haulback." In 2020, Johnson, *et al* reported northern bottlenose whale groups have been interacting with fishing vessels in the Davis Strait- Baffin Bay region of the Canadian Arctic over the last decade. Feyrer, *et al.* (2021) found photographic evidence showing steady rate of entanglement scars from unspecified fisheries around the fins of northern bottlenose whales from the Scotian Shelf between 1988-2019. Significantly higher encounter rates with northern bottlenose whales occurred during hauling, suggesting, that similar to sperm whales, they have learned to opportunistically prey on fish that escape. This study identifies that northern bottlenose whales have been engaging in an unknown level of interactions with trawlers in Newfoundland since at least 2007. This is in addition to evidence of interactions with various fisheries across the

western North Atlantic found in other studies. Whether associative behaviour with fishers is specific to trawling, certain individuals, or may be spreading among groups moving between the Arctic, Newfoundland and Scotian Shelf, is unclear and requires further study.

Photoidentification found no resights between northern bottlenose whales over the course of this study. Though conditions for photo identification were less than ideal, the minimum number of individuals (n = 23) is equivalent to ~16% of the Scotian Shelf population involved in trawl interactions, based on O'Brien and Whitehead's (2013) population estimate of ~143. Together with the sighting rates and mean group size calculated here, it suggests there are a substantial density of animals in the study area. The lack of resights also suggest that individuals are less likely than sperm whales to follow vessels between trawling events. Northern bottlenose whales on the Scotian Shelf are known to have long term high site fidelity, with low rates of movement between areas (Feyrer et al. 2021, Wimmer and Whitehead 2004). Higher encounter rates in *Playa Nova* and *La Decima* could indicate these are important areas for northern bottlenose whales. Hooker et al. (2001) suggested northern bottlenose whales were highly specialized predators, feeding almost exclusively gonatus squid. However, if northern bottlenose will readily switch to feeding around boats if the opportunity arises, it indicates whales in this area may be more generalist predators than previously assumed. Further study on the diet of northern bottlenose whales could help distinguish whether there are significant ecological differences between regions or populations.

Canada currently recognizes two sub-populations of northern bottlenose whales in western North Atlantic. The Scotian Shelf population, listed as Endangered by Canada's *Species at Risk Act*, inhabit the region off Nova Scotia and the southern Grand Banks of Newfoundland, with high site fidelity to a large submarine canyon called the Gully (COSEWIC 2011). Another concentration of northern bottlenose whales can be found in the Davis Strait and Baffin Bay; however, the size of this population is unknown (Whitehead et al. 1997). A recent genetic assessment of northern bottlenose whale population structure by Feyrer, *et al*. (2019) included samples collected near La Decima (i.e. "Newfoundland") and found this region to be an area of mixing between the Scotian Shelf and Labrador-Davis Strait populations (Feyrer et al. 2019). Our study area (from *La Décima*) in the north to *Raíz Cuadrada* in the south) lies mid-way between both populations (Figure 1). Unfortunately a review of photographic identification catalogues from the Scotian Shelf (1988-2019), Newfoundland (2016-2017) and Labrador-

Davis Strait (2003-2018) could not identify any matches between these regions and individuals in this study.

Many interactions between cetaceans and fisheries involve by-catch, entanglement or retaliation by fishers and are detrimental to the species involved (Read 2008). While the fishermen aboard the vessel at the time did not perceive a conflict, any potential risks associated with fishery interactions for northern bottlenose whales have been identified as a concern for management (Fisheries and Oceans Canada 2016). In 2017 a sperm whale was found dead in the wake of a trawler near *La Décima* during a research cruise conducted by L. Feyrer. In the case of northern bottlenose whales, fishermen related one instance where a whale was found in the codend of a trawl. However, it was in a high decomposed state and had clearly died somewhat earlier. Whales that change their feeding to associate with vessels may become dependent and vulnerable to changes in fishing practices. In addition, whale predation on escapees increases the effective catch of the fishery, which may impact estimates of bycatch losses, stock assessment and quota calculations.

Conclusions

Our results indicate that off Newfoundland sperm whales and northern bottlenose whales have learnt to associate with trawl fisheries, modifying their foraging behavior to take advantage of novel feeding opportunities. Anecdotal evidence suggests that these interactions have continued and may have spread to or from other regions. Although some studies have shown that associations with fisheries have benefitted whales (e.g., killer whales in the Crozets; (Amelot et al. 2022; Tixier et al. 2017), the energetic implications and risks of interactions for cetaceans described here are unknown and need further study.

Data for this study was collected opportunistically by the first author while working as a NAFO fisheries observer, demonstrating that there is potential for observers working on vessels to contribute to further studies with additional data collection protocols. Increasing reporting and observing requirements for international fisheries could provide critical but difficult to collect information on interactions with cetaceans and support ecosystem-based fisheries management.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

UO and JG contributed to conception and design of the study. UO wrote the first draft of the manuscript. LF contributed to the statistical analysis, writing and figures. All authors contributed to manuscript revision, read, and approved the submitted version.

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4. Table legends

Table 1. Fishing vessel activities and summary information for encounters with sperm whales and northern bottlenose whales. Encounter rates are calculated per observation period and averaged for all observations in a vessel activity state, calculated with a 95% bootstrap confidence interval.

	Preparing/ Shooting	Towing	Hauling	Navigating	Summary Total
Mean speed (knots) ± SD	5.37±2.57	3.04±0.52	1.44±0.89	6.78±2.57	-
Observational units	68	82	82	16	248
Total time observed (h)	48.9	85.0	51.6	14.3	199.8
No. encounters SW	24	24	44	2	129
No. encounters NBW	20	15	46	5	86
No. encounters both species *(included in species total)*	10	2	21	1	34
Sperm whale encounter rate ± SE (h^{-1})	0.53± 0.11	0.35 ±0.07	0.67± 0.09	0.19± 0.13	-
NBW encounter rate (h^{-1})	0.45± 0.10	0.22 ±0.08	0.73± 0.11	0.40± 0.16	-
Total no. of flukes	4	14	26	0	44
Average fluke rate ($h^{-1)}$	0.1	0.2	0.5	0	-
Max no. SW observed in an encounter	6	5	5	1	-
Mean no. SW observed per encounter ± SD	1.8±1.1	1.2±0.4	1.8±0.9	1	-
Max no. NBW observed in an encounter	5	9	5	3	-
Mean no. NBW observed per encounter ± SD	2.7±1.1	2.0±1.9	2.8±1.2	2.3±0.5	-

Table 2. Fishing areas with summary information for encounters with sperm whales and northern bottlenose whales. Encounter rates are calculated per observation period and averaged for all observations in an area, calculated with a 95% bootstrap confidence interval. Differences in summary totals due to time spent navigating between areas and values for all vessel states are included in Table 5.

	Carson Canyon	***Decima***	***Raiz Cuadrada***	***O Pequeno***	***Playa Nova***	***Divisoria***	***El Seco***	***Flemish Cap***	**Mean** (95% CI)	**Summary Total**
Total time observed (h)	23.2	12.3	1.8	28.8	82.6	7.6	18.2	10.7	22.2	185.2
Observational units	27	16	2	39	101	5	26	15	28.8	213
Number encounters SW	22	19	6	13	85	0	0	1		148
Number encounters NBW	2	11	1	22	59	2	0	1		98
Number encounters both species at same time *(included in species total)*	2	4	1	6	22	0	0	1		36
Sperm whale encounter rate (h^{-1}) ±SE	0.42± 0.12	1.08± 0.18	1.57± 0.82*	0.58± 0.18	0.63± 0.20	0.0± 0	0.0	0.10± 0.10*		-
NBW encounter rate (h^{-1}) ±SE	0.10± 0.07	0.63± 0.20	0.37± 0.38*	0.78±0.21	0.58± 0.09	0.30± 0.30	0.0	0.10±* 0.10		-
Max number SW observed in an encounter	2	1	3	2	6	-	-	-	2.8	-
Mean number SW observed per encounter	1.4±0.5	2.1±1.1	1.5±0.8	1.1±0.3	1.6±0.9	-	-	-	1.5±0.4	-
Max number BW observed in an encounter	5	9	2	5	5	1	-	-	4.5	-
Mean number BW observed per encounter	3±0	2.5±2.3	3±0	2.5±1	2.7±1.2	1	-	-	2.3±0.7	-

*Note there was only one encounter in these fishing areas

Figure 1. Map of the NAFO convention area, showing NAFO divisions, fishing areas named by fishermen and the Gully marine protected area (MPA).

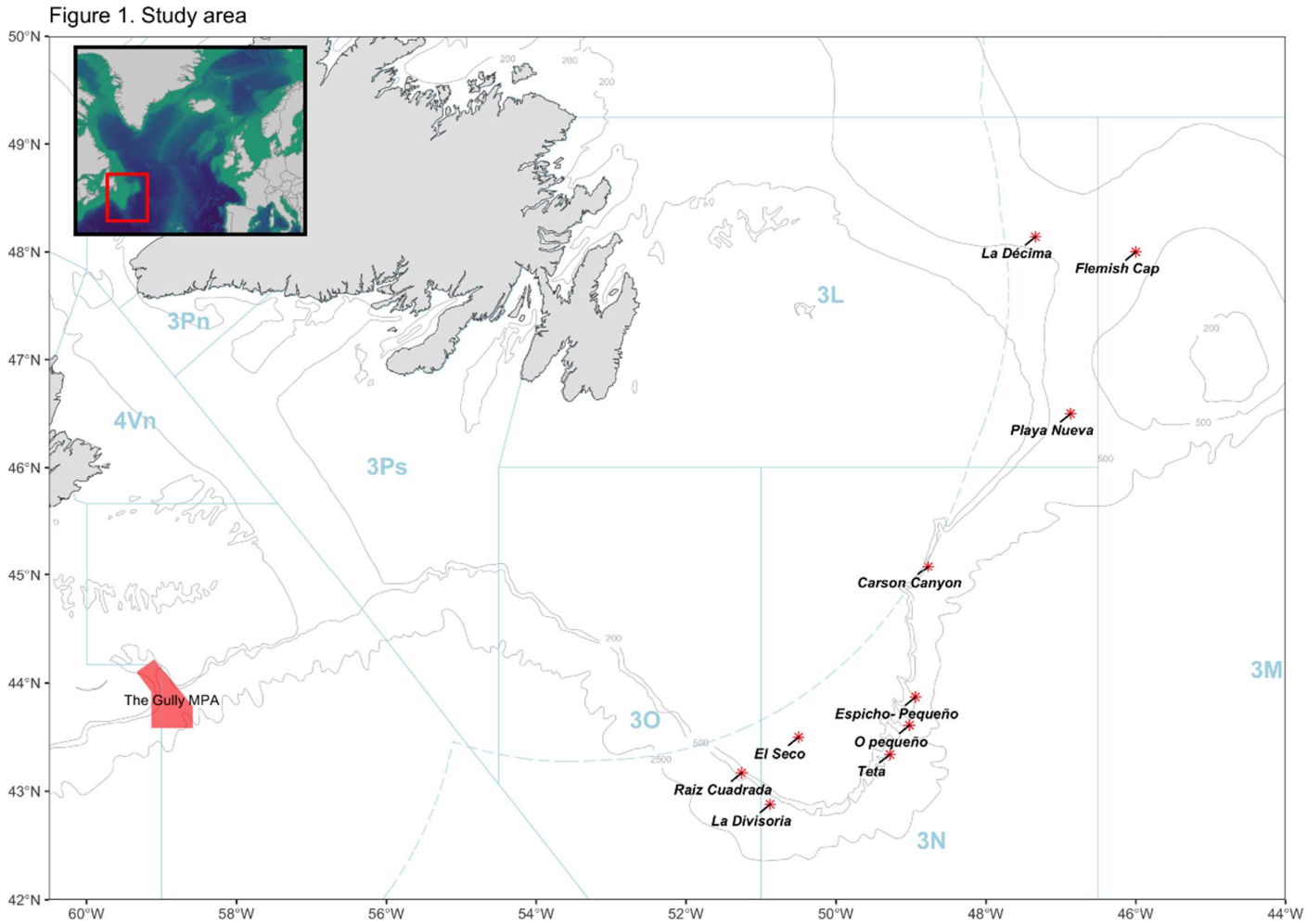

Figure 2. Four sperm whales following the vessel at the end of hauling. The mouth of the net can be clearly seen at the surface behind the yellow buoys.

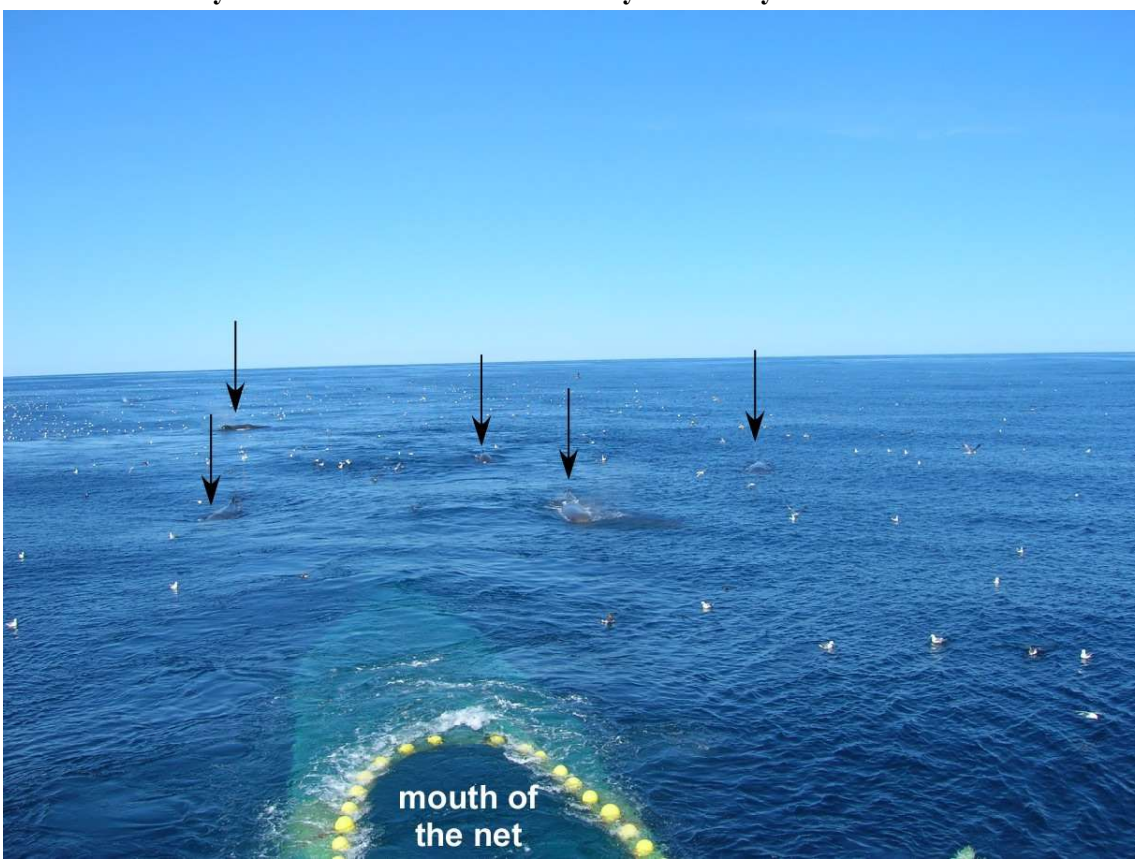

Figure 3. Sequence showing a sperm whale turning his body to the right. First picture showing his blowhole and dorsal fin, second turning to the right, dorsal fin and part of the side is observed, in the last four pictures the fluke is going to the right. In the last picture the sperm whale is almost upside down. We associated this pattern of observations with probable feeding close to the surface.

Figure 4. Sperm whale (A) and northern bottlenose whale (B) breaching. Northern bottlenose whales close to the boat at the end of hauling (C-D).

Figure 5. Whale sightings of sperm whales, northern bottlenose whales, delphinids (*D. delphis* and *G. melas*) and locations of fishing effort for shooting and hauling.

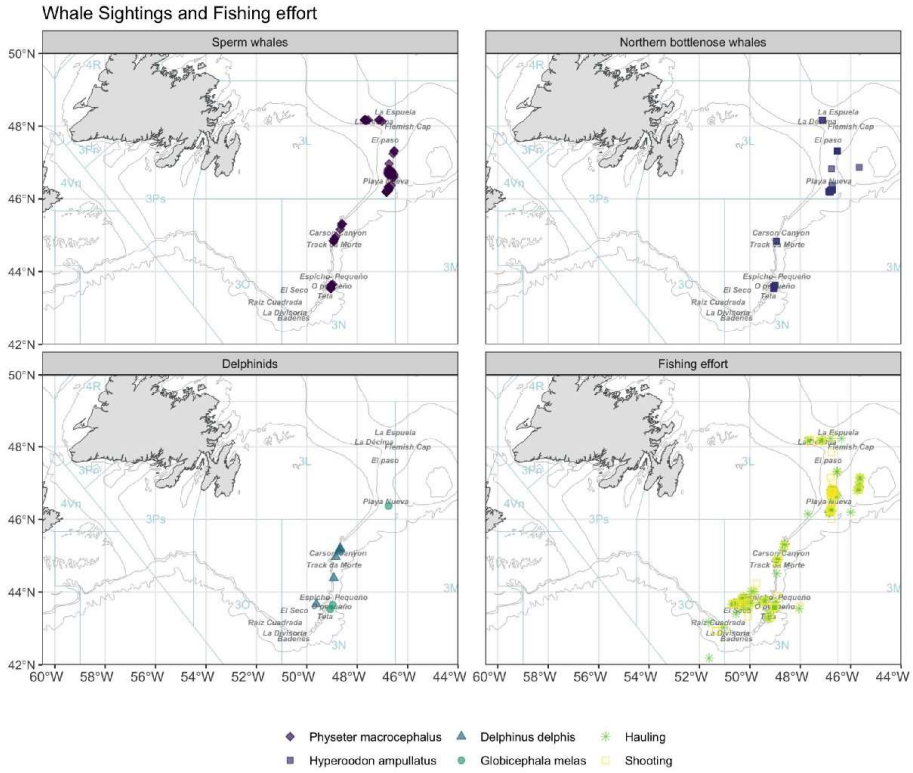

Figure 6. Whale behaviours by observational unit, fishing area and fishing activity. (A) Sperm whales (B) Nothern bottlenose whales' behavior per fishing activity. Mean whale encounter rates per (C) fishing activity and (D) fishing area. Six behaviors were scored: (1) swimming parallel to the vessel, (2) following the vessel at a constant speed and near constant distance astern, (3) swimming in the opposite direction from the vessel (normally within 50 m) (4) fluke, (5) probable feeding and (6) Breaching/lobtailing.

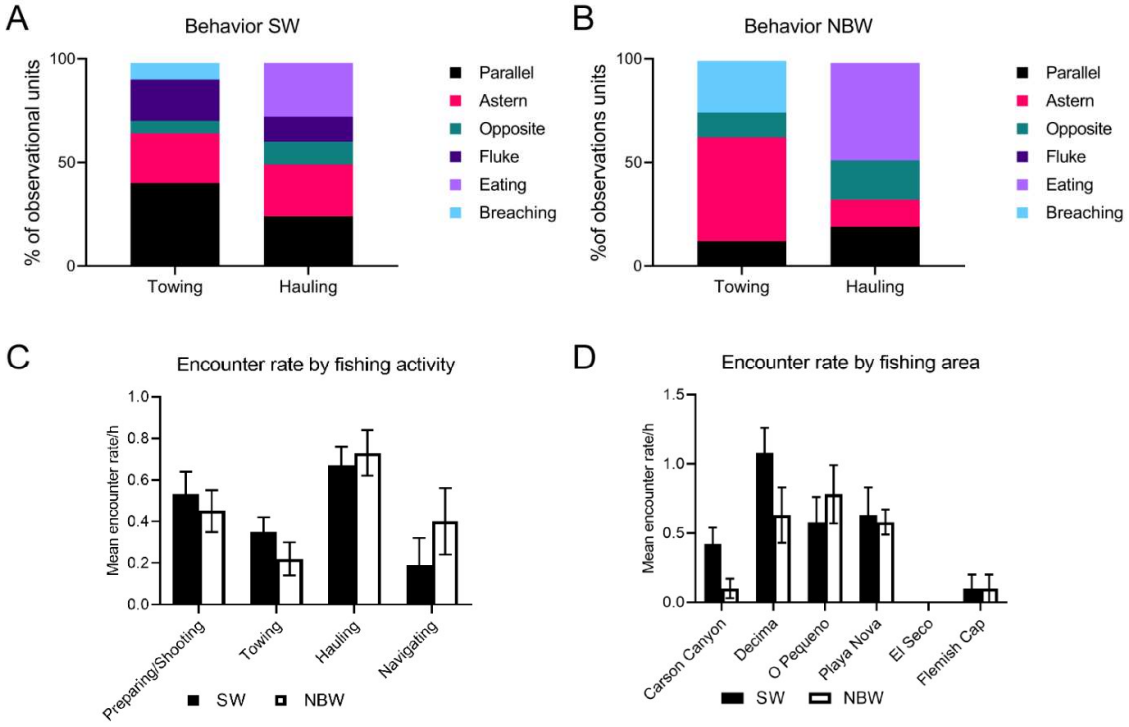
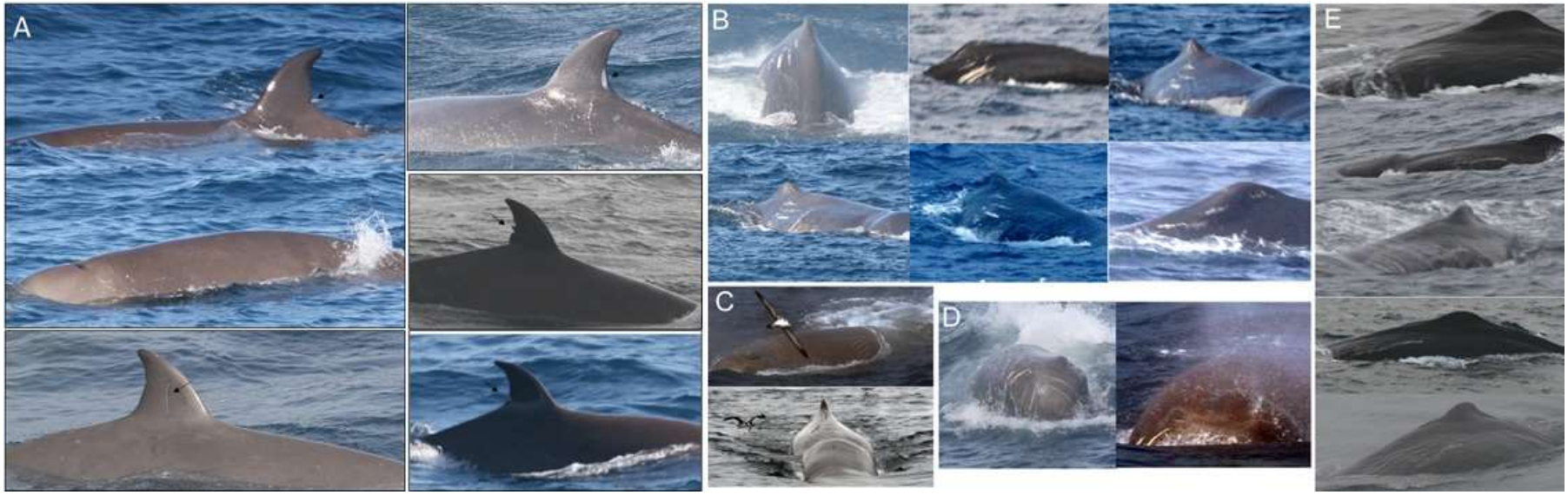
Figure 7. Examples of distinct marks used for (A) bottlenose whale identification, including notches and large fin scars and (B) for sperm whale identification. *Neboa*, with characteristic scars at both sides of the dorsal fin; *Scratchy* showed a large lateral scratch; *Breixo*, showed many scars in the front part of his head; and *Faneca*, shows a lateral scar visible only from the left side, but very easy to identify.