Sperm and northern bottlenose whale interactions with deep-water trawlers in the western North Atlantic

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Abstract

Commercial fisheries have increased in all the world's oceans with diverse unintended impacts on marine ecosystems. As a result of resource overlap, interactions between cetaceans and fisheries are a common occurrence and a conservation issue. Here, we describe the behaviors of two species: sperm and northern bottlenose whales, interacting with benthic trawlers fishing off the eastern Grand Banks of the western North Atlantic in 2007. Both species were more likely to be observed during hauling the net, where they were engaging in feeding behavior close to the surface, suggesting that whales preyed on fish escaping from the net. We identified at least seven unique sperm whales, with six individuals having multiple resights. No photographic resights of northern bottlenose whales. This study provides a foundation for managers to understand the context and nature of trawling associative behaviours in sperm and northern bottlenose whales. Given conservation concerns for recovering populations, we emphasize that more research is needed to better understand options for managing interactions with trawlers, including the potential drivers and risks of these encounters for whales.

1. Introduction

Fishing is one of the largest factors that impacts marine ecosystems (Crowder et al. 2008). Interactions between cetaceans and fisheries is a major conservation issue and the occurrence of cetacean bycatch, entanglement and depredation of commercial and small-scale fisheries have been reported worldwide (Jog et al. 2022; Read 2008). Overfishing can also indirectly threaten cetaceans, decreasing the availability of their prey (Carlucci et al. 2021). However, cetaceans may also benefit from fishing activities as the quantity and the quality of the prey consumed increases, while foraging costs decrease, providing a foraging advantage (Amelot et al. 2022). Bottom trawling accounts for 20% of global fisheries (Hiddink et al. 2017) and interactions with bottom trawlers have been observed in at least 19 species of odontocete cetaceans, including sperm whales *(Physeter macrocephalus)* and northern bottlenose whales *(Hyperoodon ampullatus)* (Bonizzoni et al. 2022).

In the western North Atlantic, deep diving sperm whales and northern bottlenose whales have anecdotally been known to interact with trawlers targeting species such as Greenland halibut (*Reinnhardtius hippoglossoides*) (Hooker et al. 2001; Johnson et al. 2020). Due to the recently implemented Import Provisions of the United States *Marine Mammal Protection Act*,

understanding the potential for marine mammal bycatch is of interest to fisheries managers worldwide (Wade et al. 2021). Additionally, due to their small population size, and Endangered status under Canada's *Species At Risk Act (SARA 2006)*, research on the risks of fisheries to the Scotian Shelf population of northern bottlenose whales and the development of mitigation measures where necessary, has been identified as a management priority (Fisheries and Oceans Canada, 2016).

Responsible ecosystem-based management (EBM) of fisheries requires detailed knowledge of interactions with non-target species, such as cetaceans. For EBM strategies to be effective, managers need to understand the real and perceived impacts on fisheries and whales. This requires identifying the cetacean species involved, the fisheries and marine areas where interactions are most prevalent, and any long-term trends in interactions. In this study we describe sperm and northern bottlenose whales' interactions with trawlers in the western North Atlantic in 2007 to increase understanding of the mechanics, prevalence, and risks of this associative behavior. Our specific aims are to: (1) identify areas of overlap between fishing activities and sperm and bottlenose whales, and (2) investigate the influence of fishing activities on the presence and behaviour of these species.

2. Material and Methods

2.1 Study area

The study area is located between the western and southern margins of the Grand Banks of Newfoundland in the western North Atlantic (**Figure 1**). 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. The trawler operated in four NAFO divisions: 3L, 3M, 3N and 3O. Fishermen had vernacular names for their preferred fishing areas, where they typically target different species **(Table 1).** 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 **(Table 1).** Other than towing depth, there was no significant variation in the method of fishing among target species (Greenland halibut, redfish (*Sebastes sp.),* or thorny skate (*Raja sp*.).

The study area is located between the two sub-populations of northern bottlenose whales in western North Atlantic recognized by Canada. The Scotian Shelf population inhabits a region off Nova Scotia and the southern Grand Banks of Newfoundland, with high site fidelity to a large submarine canyon called the Gully (Stanistreet 2021). Another concentration of northern bottlenose whales can be found in the Davis Strait and Baffin Bay area; however, the size of this population is unknown (Whitehead et al. 1997). Most sightings of sperm whales observed in the North Atlantic are single individuals, or more rarely small groups of males. Higher number of sperm whales are found along the shelf edge, with occasional sightings in shallower regions (Whitehead et al. 1992).

In the study area, most sightings of sperm whales 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, a recent study by Kobayashi et al. (2020) describes the long-term associations in male sperm whales in the North Pacific, suggesting that male groups may serve to enhance foraging success or provide protection against predators.

2.2 Field observations

Observations on cetacean encounters were collected on 50 days, between the 20th of July and the 13th of September in 2007, by UO while working as a NAFO observer on the 51 m stern trawler *Playa Menduiña Dos*. Data collection, analysis and publication of this study was conducted with the vessel captain's consent. Observation effort for this study was collected opportunistically during any of the unscheduled time available (excluding NAFO fishery observer duties and rest periods), with an attempt to balance the number of observation periods/time between the different vessel activities. Observations of cetaceans were typically made from the vessel's bridge during the day, with some behavioral observations occurring at night when whales were within 30 m of the boat. Nighttime observations relied on the vessel's lights, which were directed astern to allow the cod end to be monitored as the net was hauled to the surface.

Data collection was carried out during the four types of vessel operations (**Table 2**). The distance between the trawler and the net varied depending on the fishing area and depth. Trawler speed varied depending on fishing activity (**Table 1**). Information recorded during

each observation period included the trawler location, speed, trawling activity, cloud cover, water temperature, sea state, and visibility. Although effort directed at recording cetaceans was opportunistic (occurring outside scheduled NAFO observer duties), standard data collection protocols were used, and effort was made to distribute observation periods across all fishing activities.

2.3 Sperm and northern bottlenose whale data collection

Data on both sperm and northern bottlenose whales were collected during observation periods (~30 minutes, during one type of trawler activity), using two field protocols (1) scan sampling for whale presence and behaviour every ten minutes and (2) recording the duration of cetacean encounters. During a scan sample the entire 360° area around the trawler was scanned visually for the presence of whales. Data was recorded on whale species and group size. Whale behaviors (**Table 3, Figure 3, Figure 4**) were recorded when observation conditions allowed (animals within 300 m, sea state < Beaufort 4).

Observed whale encounters began when whales were sighted at the surface during an observation period and ended when 10 minutes had elapsed without a sighting (sensu (Gowans et al. 2001). When possible, identification 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. 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.

2.4 Photo-identification analysis

Photo identification was used to accurately identify individuals, group size, understand associations between species and trawling activities, and information regarding the distribution of whales. Individual whales can be reliably identified from various identifying nicks, scars and marks, on the trailing edge of the flukes (sperm whales) and the melon, back and dorsal fin (sperm whales and northern bottlenose whales) (Arnbom 1987; Gordon et al. 1992). Comparisons between photographs collected within this study period used identifying marks that could be seen anywhere on an individual's body (i.e., backs, dorsal fins, melons, flukes) to distinguish individual whales. Matching with northern bottlenose whale photographic catalogues external to this study only considered marks that are known to be

persistent and reliable for long-term identification (e.g., notches, back indents (Feyrer 2020). Images of northern bottlenose whales were quality (Q) rated based on established criteria for photographic identification (Feyrer et al. 2021) and only images of Q3 or above were included in matching between catalogues.

Associations between individual sperm whales were defined by co-occurrence within the same observation period. Where the same photographic perspective on an identifying mark could be compared (e.g., tail fluke), individuals were identified across encounters. Sperm whale fluke photographs were added to Flukebook to confirm unique IDs within this dataset using computer assisted algorithms designed for sperm whales (Blount et al. 2022). We calculated the minimum speed of the identified sperm whales by dividing the distance between two consecutive resights dividing by the elapsed time between them.

2.5 Statistical analysis

Observed encounter rates were calculated by dividing the number of encounters by the length of each observation period. The average observed encounter rates were calculated for each trawler activity state and each area. To assess the relationship(s) between different fishing areas and trawler activity state on whale presence we used binomial generalized linear models (GLMs). The response variable was presence or absence of whales during observation periods with model terms for fishing area, trawler activity state, sighting conditions (i.e., Beaufort Sea state, visibility (m), cloud cover (%) and daylight), and an offset for effort (length of 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 trawler was travelling, were excluded to avoid model separation due to singularities. Dispersion and zero inflation of all GLMs were checked with the DHARMa package (Hartig, 2017), which approximates dispersion and zero inflation via simulations.

The mean rate of sperm whales ‘fluke ups’ was calculated by dividing the number of ‘flukes up’ in an observational unit and divided this by the total time for that unit of observation. The fluke-up rates of sperm whales, which suggests whales are diving down to feed on fish were compared for each trawler activity state, using Kruskal Wallis and Tukey test. All statistics were completed in R (R Core Team 2018).

3. Results

Overall, 200 hours of different fishing activities were monitored over 50 days. The majority of the observation effort was evenly distributed between the hours of 8:00 - 12:00 am, 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 transiting between sites **(Table 4)**. Observational effort occurred during 104 hauls (81.25%) of the 128 net deployments made by the vessel during the study period. Observations were made during all types of trawling activity. The total hours of observation, trawler speed and whale behavior during each trawling activity is summarized in **Table 5**. 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 1**.

3.1 Whale sightings

We observed four species of cetaceans: common dolphins (*Delphinus delphis*, N = 6 encounters), long-finned pilot whales (*Globicephala melas*, N = 3 encounters), sperm whales (N=129 encounters) and northern bottlenose whales (N=86 encounters). Northern bottlenose whales and sperm whales were the only species observed interacting with the trawl and were seen together on 34 occasions with no apparent surface interactions **(Figure 4)**. This included 14 hauls made at night, where there were four encounters with sperm whales and six encounters with northern bottlenose whales. Whale behavior at nighttime was similar to that observed during hauling in the daytime (i.e., surface feeding, fluke ups). Datasets used for modelling trends in observed encounters are available as part of the open access data repository for this publication (Oyarbide and Feyrer 2022).

3.1.1 Whale presence across fishing areas

Sperm and bottlenose whales were both observed in four fishing areas: *La Décima* (3L), *Playa Nova* (3L), *Carson Canyon* (3N) and *O Pequeno* (3N), while 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 species 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*) **(Figure 5)**.

Across this study, an average of 1.5 sperm whales were sighted during an observed encounter. *La Décima* had the highest average sperm whale observed encounter rate of 1.08/hr. of observation, while the largest group size of sperm whales (N = 6 individuals) was observed in *Playa Nova.* For northern bottlenose whales, observed encounter rate was highest (0.78/hr. of observation) in *O Pequeno*. The maximum number of northern bottlenose whales in an observed encounter was 9, in *La Décima*, and the mean number of individuals across all observed encounters was 2.3 (**Table 4, Figure 6**).

3.1.2 Whale behavior and trawler activity states

The behavior of both sperm and northern bottlenose whales differed with trawler activity, particularly between towing and hauling (**Table 5**). During towing sperm whales were often observed swimming parallel to and either abeam or astern of the trawler maintaining a constant speed and distance **(Figure 4).** The longest sighting of a sperm whale, one hour and 25 minutes of continuous observation, occurred during towing. Surface feeding behavior was not observed during towing but lobtailing and repeated breaching was observed on one occasion (**Figure 3)**. Northern bottlenose whales disappeared soon after shooting the net but were often observed swimming behind the net as it was being hauled. On two occasions repeated breaching was observed while towing (**Figure 3B**). Feeding behavior on discards was not observed during towing (**Table 2**).

During hauling, the boat slows down, and the net winches generate a loud noise and vibration in the hull. At this time, both sperm whales and northern bottlenose whales were observed astern, swimming towards the trawler, or surface feeding. Sperm whale "fluke ups" were observed five times more often during hauling, than preparing/shooting, and ~2.5 times more often than towing (Kruskal-Wallis test, Tukey HSD $p<0.05$, N=248). The fluke-up rate per hour was significantly higher during hauling (0.5 fluke-ups per whale) than during preparing/shooting and towing (Kruskal-Wallis test, Tukey HSD $p<0.05$, N=248) (**Table 5**). The surface feeding behavior described in this study, was only observed at the end of hauling, once the cod end was close to the surface, coinciding with observations of birds feeding on escaping fish at the surface. Overall, observed encounter rates for both sperm whales and northern bottlenose whales was significant higher during hauling than all other activity states (**Figure 6C**).

3.1.3 Whale presence, fishing area and trawler activity states

Fishing area and trawler activity state were both significant terms in modelling northern bottlenose whales and sperm whale presence. Sighting condition variables were also significant in the observed presence 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 6 A, B**). Inspection of coefficients indicated that *La Décima* 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 Cuadrada* and *Divisoria,* were not included in the models due to low observation effort (**Table 1**). All trawler 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 6**). Transiting between areas was not included in GLMs as there was no corresponding region associated with the activity.

3.2 Photo identification analysis

A total of 7,343 photographs were taken during whale encounters and individuals were identified using distinctive markings. Twenty-three northern bottlenose whale individuals were identified based on photographs of the right-side dorsal fins and 15 other individuals were identified from left-side dorsal fin (**Figure 7**). None of the northern bottlenose whales identified were seen in consecutive hauls or on more than one day.

A total of seven sperm whales were identified using markings on their tail flukes, with an additional three whales identified solely by distinctive marks on their bodies **(Figure 7 and Table 7**). These ten distinctively marked individuals were named for the observer's reference and tracking within encounters (**Figure S1, S2**). However, due to the non-overlapping photographic perspective of individuals, duplicate identifications could have occurred across all encounters in this study. Thus, the minimum number of individual sperm associating with the trawler, as determined by distinct markings on the tail fluke, and confirmed using Flukebook's identification algorithms was seven. Photographs of sperm whales encountered in this study are publicly available to other researchers through the Flukebook platform.

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 7**, **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*; the maximum distance between two sightings of an individual sperm whale in this study. 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**).

4. Discussion

Here we describe the behavioral associations of sperm and northern bottlenose whales with trawling activities in the western North Atlantic, supporting a history of anecdotal observations made by fishermen prior to this study and cetacean researchers in the area in 2016-2017 (Marotte 2017). Whales were most frequently encountered when the trawler was engaged in hauling while targeting Greenland halibut, which occurred in deep waters close to the continental shelf break, characteristic of habitat identified for these species (Gomez et al. 2017; Stanistreet 2021).

While we did not document the underwater mechanics of the whale's foraging strategy, both species appeared to increase their association with the trawler during observations of hauling. Additionally, both species engaged in surface feeding behavior and sperm whales increased their rate of fluke ups. Observed increases in whale's association with hauling does not rule out potential foraging during towing, as the net is further away, and surface behavior may be limited while the net is at depth and harder to observe. While towing, fish escaping the minimum mesh size (135mm in these NAFO areas), are estimated to be a reasonable size. Retention probability has been calculated as 0.5 for Greenland halibut with a body length of 42cm, and 100% retention doesn't occur until fish are ~55cm long (Huse et al. 1999). Escapees associated with towing, particularly fish that are disoriented or disabled, may also be easier to detect (i.e., either visually or acoustically) than other naturally occurring prey. Opportunistic associations between cetaceans and fishing vessels are thought to not only increase prey encounter rates, but also reduce energetic costs associated with greater dive

depths (Amelot et al. 2022). Such energetic incentives are likely to contribute to increasing the number of whales that forage opportunistically in association with fishers in this and other areas (Amelot et al. 2022).

Feeding on discards and offal is the primary foraging behavior described for both sperm and northern bottlenose whales associating with Greenland halibut fisheries in the Arctic (Johnson et al 2020, DFO unpublished data). However, discard predation by whales was not observed in this study. The catch is processed by the crew just after the trawler doors are dropped into the water (early shooting) and depending on the size of the haul, it can take several hours to process (after hours of towing). During this period discards are released from the posterior port side of the trawler. Whales were not seen in this area or in association with the timing of discards. This suggests differences in fishing practices (i.e., over time or between regions) may change whale behavior or increase the timing and types of associations with fishing activities. Understanding these differences could reflect an opportunity for management and risk mitigation for whales that associate with these fisheries.

Sperm whales

Karpouzli & Leaper's earlier research on interactions between sperm whales and benthic trawlers in the same area in 1997 did not document any interactions with northern bottlenose whales. In addition, their study showed a pronounced difference in sighting rates with encounter rates high during hauling (0.61 sightings per hour), but very low during shooting and towing (~0.02). Here, sighting rates during hauling were similar (0.73 sightings per hour), but higher during shooting (0.78) and towing (0.63).

An increase in encounters during hauling could reflect a learned behavior, or an observational bias. As the net gets closer, any animals associating with it will be easier to see from the vessel. However, hauling was also associated with a significantly higher fluke up rates for sperm whales; this distinct behavioral change, where the frequency of dives intensifies, also supports our interpretation that opportunistic foraging increases during hauling. Whether and how whales may be engaging in foraging during other fishing activities, such as preying on the fish escaping the net during towing or entering the net, requires further research (e.g., using trawl cameras (Santana-Garcon et al. 2018).

Six of the photo-identified sperm whales were resighted during multiple encounters, even though conditions for photo-identification were far from ideal. It is possible that these individuals followed the vessel through the different trawling activity states, in some cases over periods of several days. The average speed of the trawler during fishing activities (e.g., 5.4 km/h shooting and towing, 1.44 km/h hauling), would allow the whales follow 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). 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 whales intentionally followed the trawler or moved between sites on their own accord. However, in the case of *Breixo*, it seems probable he moved independently as no sperm whales were observed between identifications.

Photographs of sperm whale flukes from this study have been submitted to Flukebook (Levenson et al. 2015), an image analysis tool for photoidentification used by international sperm whale researchers to understand the movements, social associations and population dynamics of sperm whales across the world. The photos taken here were all confirmed unique IDs within this study area and are now available for all users of that platform to examine potential matches across the Atlantic. As demonstrated in this study, photographs taken by fisheries observers have the potential to increase our knowledge of cetaceans in remote and otherwise hard to study regions of the ocean.

Sperm whales males tend to be solitary or in small groups at high latitudes, coordinated behavior involving multiple male sperm whales has been observed on rare occasions. The mean group size of 1.6 observed in this study is higher than sperm whales in other areas in the North Atlantic (e.g., 1.1 for Whitehead *et al.* 1992; 1.2 for Weir *et al.* 2001), but smaller than the group size of 2.2, found in an earlier study of the same area by Karpouzli & Leaper (2004). Here, the maximum group size of sperm whales was six, suggesting the presence of fishing trawlers is facilitating larger than average groups. Given the evidence that social learning can increase the incidence of cetacean depredation and foraging associations with fisheries (Schakner et al. 2014) , further study is needed to understand whether and how social transmission may be a factor in this area.

Northern bottlenose whales

As there are no other published records of northern bottlenose whales associating with fisheries off Newfoundland prior to 2007, here we document the first behavioral records in an area located between two known population centers in the western North Atlantic. Although northern bottlenose whales are known to be curious and approach vessels (Feyrer et al. 2021; Gray and Flower 1882), there are very few other reports of interactions between northern bottlenose whales and fishing trawlers in the western North Atlantic. 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 (from 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 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. Whether associative behavior in northern bottlenose whales is specific to trawling, certain individual whales, or may be spreading as the western Atlantic populations recover and potentially increase movements between the Arctic, Newfoundland, and the Scotian Shelf, is unclear and requires further study.

Photoidentification found no resights between northern bottlenose whales over the course of this study. Here, the minimum number of unique individuals identified (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, it suggests there is 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 trawlers 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; Stanistreet 2021). Higher observed encounter rates in *Playa Nova* and *La Décima* 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 whales will

switch to feeding around fishing vessels if the opportunity arises, it indicates this species may be a more generalist predator 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.

The study area occurs in the border region between the two sub-populations of northern bottlenose whales in the western North Atlantic - the Scotian Shelf and Davis Strait-Baffin Bay population. A recent genetic assessment of northern bottlenose whale population structure by Feyrer, *et al*. (2019) included samples collected near *La Décima* (i.e., "Newfoundland") and found this region to be an area of mixing between the Scotian Shelf and Labrador-Davis Strait populations. Our study area, from *La Décima* in the north to *Raíz Cuadrada* in the south, lies mid-way between both populations (Figure 1). A review of the photographic identification catalogues from the Scotian Shelf (1988-2019), Newfoundland (2016-2017), and Labrador-Davis Strait (2003-2018) found no matches with individuals photographed in this study.

Many interactions between cetaceans and fisheries are detrimental to the species involved, as whales can face consequences including by-catch, entanglement and retaliation by fishers (Read 2008). While the fishermen aboard the trawler 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 northern bottlenose whale was found in the cod end 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 trawlers may also become dependent and vulnerable to changes in fishing effort or practices. In addition, whale predation on escapees increases the effective catch of the fishery, which is not considered in estimates of bycatch losses, stock assessment and quota calculations.

Conclusions

Our observations and analysis suggest that sperm whales in the study area have continued and possibly increased their associations with trawl fisheries, modifying their foraging behavior. Meanwhile northern bottlenose whales, not previously documented to interact with trawlers

in the study area, have learnt to take advantage of novel feeding opportunities, as they have in 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 by the first author while working as a NAFO fisheries observer, demonstrating that fisheries observers can effectively record additional data on cetacean interactions valuable for research and management. Information on fishery interactions with cetaceans is otherwise rarely available and improving observer reporting requirements for international fisheries could provide critical data necessary for supporting 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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Pitanxo sank February 15, 2022, fishing in the same waters where this study took place, killing twenty-one, including the observer, and leaving three survivors. We would like to acknowledge the contributions of fishers and observers everywhere to increasing our knowledge and understanding of rare marine species and ecosystems.

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5. Table legends

Table 1. Target species and summary information for each fishing area. Target species varied between areas and included: Greenland halibut (*Reinhardtius hippoglossoides*), Thorny skate (*Raja sp.), and* Redfish (*Sebastes* sp). Other species such as grenadiers (*Macrourus spp*), American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*), yellowtail (*Limanda ferruginea*), white hake (*Urophycis tenuis*) and cod (*Gadus morhua*) were also taken.

Table 3. Whale behaviour definitions. SW = sperm whale, NBW = northern bottlenose whale.

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Table 5. Fishing trawler 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 trawler activity state, calculated with a 95% bootstrap confidence interval.

Table 6. Summary of binomial generalized linear regression models (GLMs) used to assess the effect of trawling activity, region and sighting conditions on observations of (A) sperm whales or (B) northern bottlenose whales. Greatest support for best fit models is indicated by lowest ΔAIC (Akaike's information criterion) values; all model with ΔAIC < 2 indicated in bold. Coefficients from the most supported model are provided, and terms where support for a significant relationship (positive or negative) with whale presence (p-value <0.05) are noted in bold. For Trawler Activity state, Towing was the reference level and for Fishing Area, Flemish cap was the reference level**.**

Figure legends

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. 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 surface feeding close to the surface.

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Figure 3. Sperm whale (A) and northern bottlenose whale (B) breaching. Northern bottlenose whales close to the boat at the end of hauling (C-D).

Figure 4. Examples of whale behaviors. **(A)** and **(B)** Sperm and northern bottlenose whales seen together. **(C)** Five sperm whales following the trawler at the end of hauling with the mouth of the net visible at the surface behind the yellow buoys. Red stars indicate sperm whales and yellow stars indicate northern bottlenose whales**.** Black arrows shows sperm whales

Figure 5. Location of hauling and shooting effort in relation to sightings of sperm whales and northern bottlenose whales.

Figure 6. The occurrence of the different whale behaviours versus fishing area and trawler activity. (A) Sperm whales **(B)** Nothern bottlenose whales' behavior per trawling activity. Mean whale encounter rates per **(C**) trawling activity and **(D)** fishing area. Six behaviors were scored: (1) swimming parallel to the vessel, (2) following the trawler at a constant speed and near constant distance astern, (3) swimming in the opposite direction from the trawler (normally within 50 m) (4) fluke, (5) surface 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.

Supplementary Data

Table S1. Summary of sperm whale photo id data, showing date, haul number, time, fishing area, trawler activity and speed for each encounter. Trawler activity codes: (H) Hauling (P/S) Preparing/Shooting (T) Towing

Figure S1. Associations between identified sperm whales. The arrows show the presence of both individuals together near the vessel, and the number of times the whales were seen together. *Breixo* (middle) was seen with all the other animals**.**

Figure S2. Location of sightings of individual sperm whales in (A) the entire study area and (B) an inset of concentrated sightings in the Flemish Pass.

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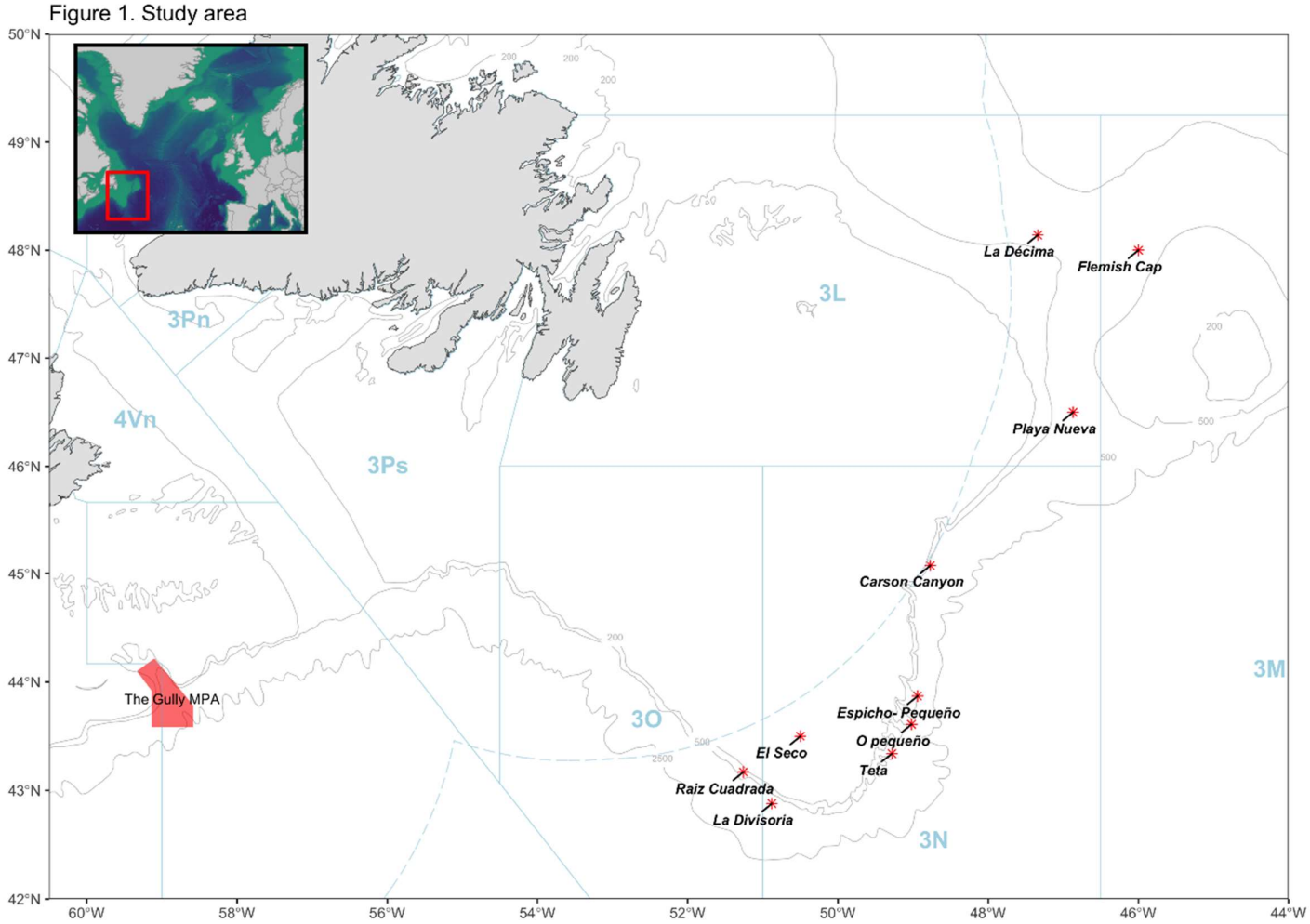

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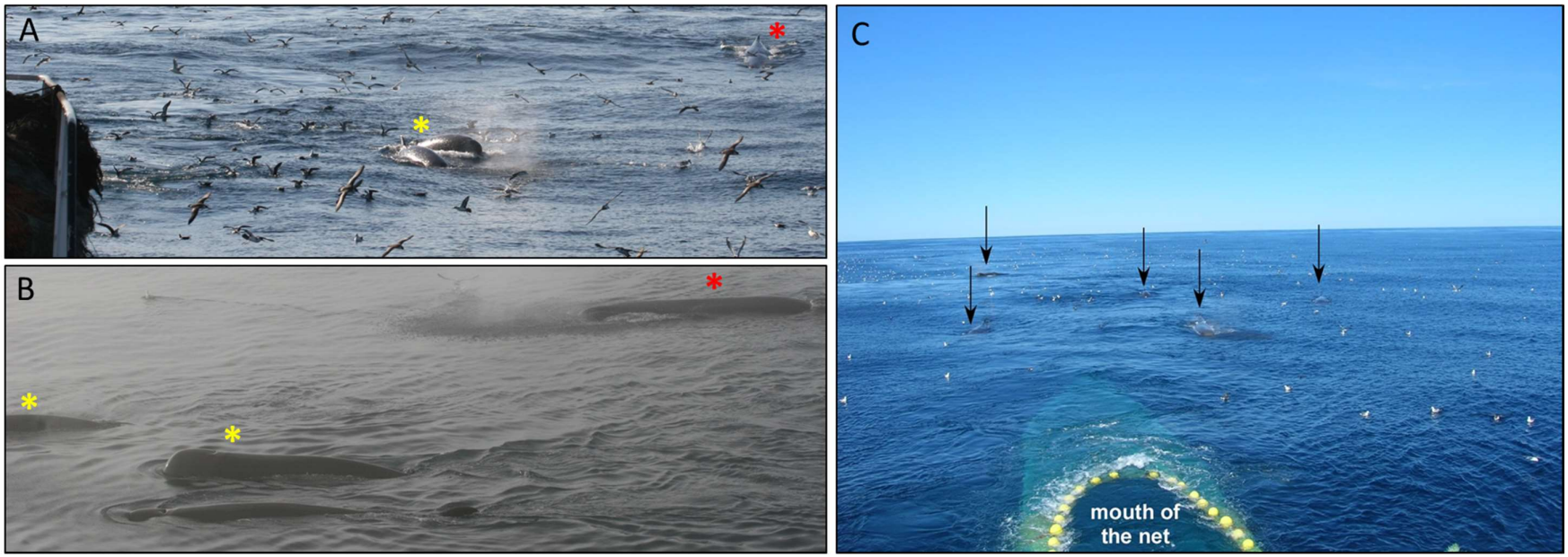

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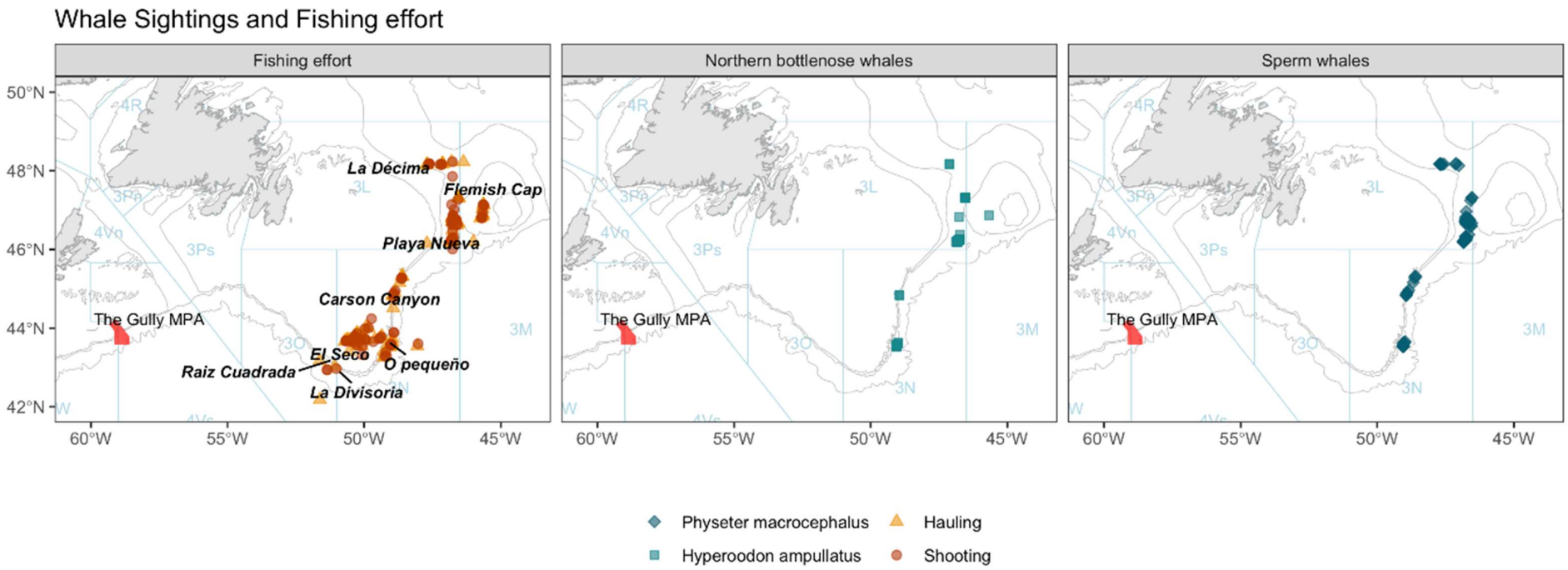

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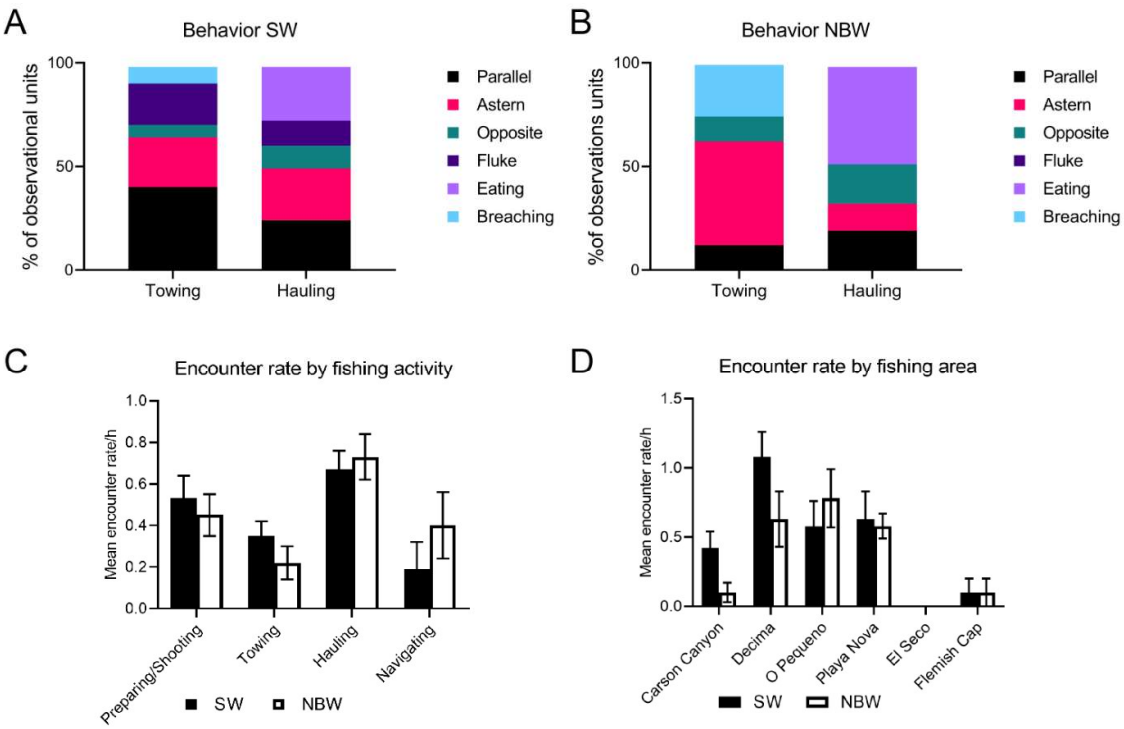

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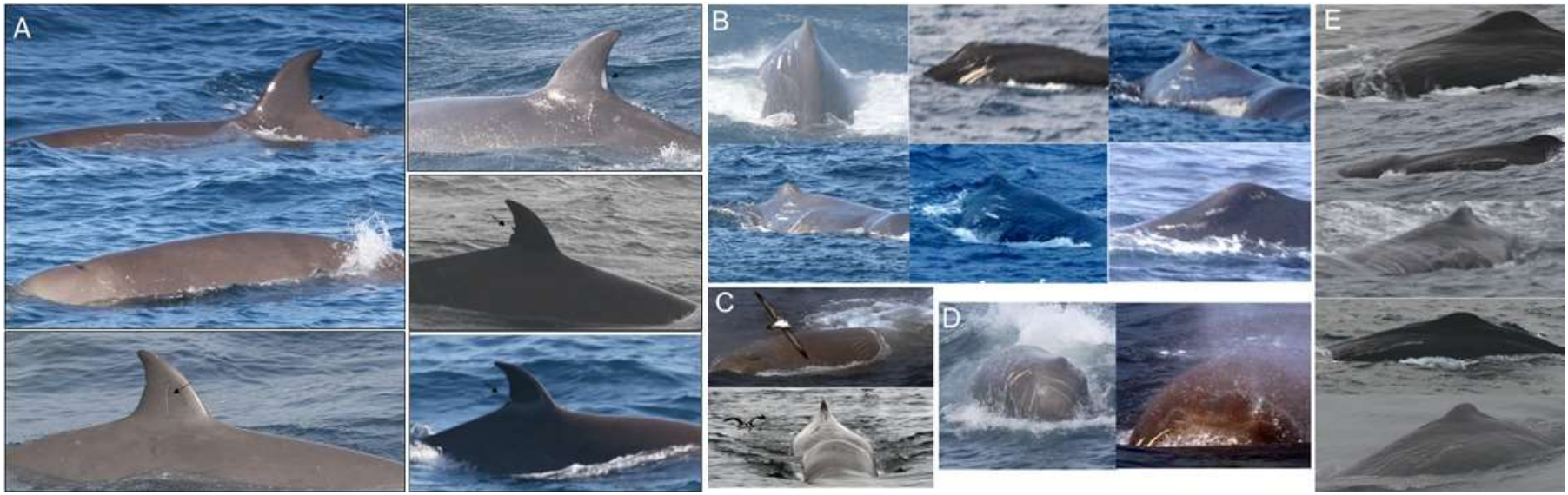

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NAFO | Fishing Area		**Target Species**	**Depth Range (m)**	**Tow Cable Length (m)**	**Towed Net Distance (m)**	**Mean Haul Duration (h)**	**Average Haul Length (km)**	**Hauls Observed (N)**	**Observation Periods (N)**	**Observation Time (h)**
3L	*La Décima*	Greenland halibut	750-1400	2500-2700	2377±127	7.3±1.2	36	10	16	12.9
	Playa Nova		750-1450	2200-2700	2264±186	10.6±1.9	59	48	101	90
3N	*O Pequeno*	Greenland halibut	500-1450	1700-2800	2301±332	55.4±1.3	46	21	39	31.2
	Carson Canyon		700-1300	2000-2400	1957±118	8.4±2.4	25	12	27	24.9
	El Seco	Thorny skate	50- 90	340	331±4	4.9±1.6	-	25	26	21
3O	*Raíz Cuadrada*	Greenland halibut	900- 1100	2500	2281±60	11.6±4.9	32	2	2	10
	Divisoria	Redfish	550	600	1775	11		1	4	0.6
3M	*Flemish Cap*	Redfish	50-800	850	797±11	4.5±1.9	18	9	15	11.6
-	*Transiting*	NA	-	-	-	-	-	-	16	14.3
Total								**128**	**248**	**202.2**

Table 2. Description of trawler activity states and opportunistic prey availability during each activity

Trawler activity	Activity Description	Opportunistic Prey Available
Preparing/ shooting the net	After hauling, the fishermen quickly inspect the net for damage. Some of the crew start processing the fish, releasing bycatch and discarding offal. Once the net has passed inspection, the other crew begin the next net deployment, a process that can take 1- 1.5 hours. During the initial process of deploying the fishing gear to the seabed, the trawler is stopped or moving at very low speed. Shooting commences with the cod end being launched over the stern, then the net is let out as the vessel steams slowly ahead. The trawl doors are attached to the gear and the warps slacked away from the winch until the gear is in position on the seabed. The trawl doors provide the horizontal spread of the net. The trawler moves slowly ahead and once the trawl doors are in the water, the rest of the crew proceed to process the remaining fish. Shooting ends when the net reaches the seabed, which can vary based on depth.	• Discards of bycatch and offal from target species
Towing	The action of trawling the fishing gear along the seabed. During towing the crew are still processing the fish.	• Discards of bycatch and offal from target species • Escapees from the net
Hauling	The process of retrieving the fishing gear after towing. The vessel trawl winches haul the net and lift the cod-end containing the catch on board from the stern over the deck. The winches generate an intense noise and vibration in the hull when working.	• Escapees from the net
Transiting	Navigating to other fishing areas.	• None

Table 3. Whale behaviour definitions. SW = sperm whale, NBW = northern bottlenose whale.

Whale behavior	Definition	Species
Swim parallel	Swimming alongside and at the same speed as the trawler.	**SW**
Following	Swimming astern the trawler at a constant speed and distance (**Figure 2**).	**SW, NBW**
Swimming in an opposite direction	Swimming with no apparent association with the heading of the trawler.	**SW, NBW**
Fluke up	Tail fluke is raised high into the air, indicating a steep dive.	**SW**
Surface feeding	Typically observed during the final stage of hauling when the cod end was close to the vessel's stern and fish were observed escaping the net as seabirds (e.g., great shearwaters; *Ardenna gravis,* northern fulmars; *Fulmarus glacialis*) brought them to the surface.	**SW, NBW**
	Slowly turns body sideways or upside down just below the surface, showing first the dorsal fin, then the blowhole, and finally, their whitish jaw.	**SW**
	Makes repeated short shallow dives, during surfacing, with their beak frequently visible	**NBW**
Breach	A thrusting leap out of the water where at least 40% of the animal's body is in the air (**Figure 3**).	**SW, NBW**
Lobtail	Energetic tail slaps at the surface.	**SW, NBW**

Table 4. 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 transiting between areas and values for all trawler states are included in Table 5.

	Carson Canyon	***La Décima***	***Raiz Cuadrada****	***O Pequeno***	***Playa Nova***	***Divisoria***	***El Seco***	***Flemish Cap****	**Mean** (95% CI)	**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 observed encounters SW	22	19	6	13	85	0	0	1		148
Number observed encounters NBW	2	11	1	22	59	2	0	1		98
Number observed encounters both species at same time *(included in species total)*	2	4	1	6	22	0	0	1		36
Sperm whale observed 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 observed 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	-

*Only one encounter in these fishing areas

Table 5. Fishing trawler 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 trawler activity state, calculated with a 95% bootstrap confidence interval.

	Preparing/ Shooting	**Towing**	**Hauling**	**Transiting**	**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. observed encounters SW	24	24	44	2	129
No. observed encounters NBW	20	15	46	5	86
No. observed encounters both species *(Included in species total)*	10	2	21	1	34
Sperm whale observed encounter rate ± SE (h^{-1})	0.53± 0.11	0.35 ±0.07	0.67± 0.09	0.19± 0.13	-
NBW observed encounter rate (h^{-1})	0.45± 0.10	0.22 ±0.08	0.73± 0.11	0.40± 0.16	-
Total no. of observed 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 6. Summary of binomial generalized linear regression models (GLMs) used to assess the effect of trawling activity, region and sighting conditions on observations of (A) sperm whales or (B) northern bottlenose whales. Greatest support for best fit models is indicated by lowest ΔAIC (Akaike's information criterion) values; all model with ΔAIC < 2 indicated in bold. Coefficients from the most supported model are provided, and terms where support for a significant relationship (positive or negative) with whale presence (p-value <0.05) are noted in bold. For Trawler Activity state, Towing was the reference level and for Fishing Area, Flemish cap was the reference level**.**

(A)

Sperm whale presence	**df**	**AIC**	**ΔAIC**
~ 1 (Null)	224	407.7	169.1
~ Vessel.Activity:Fishing.Area + Vessel.Activity + Fishing.Area + Cloud+ SEA+VIS + Daylight	14	256.3	17.7
~ Vessel.Activity + Fishing.Area + Cloud+ SEA+VIS + Daylight	11	240.7	2.1
~ Vessel.Activity + Fishing.Area + SEA+VIS + Daylight	**10**	**239.2**	**0.6**
~ Vessel.Activity + Fishing.Area + SEA+VIS	**9**	**238.6**	**0**

~ Vessel Activity + Fishing Area + Visibility + Sea state				
Coefficient Terms	Estimates	std error	Statistic	p value
T (Intercept)	**-4.92**	**1.21**	**-4.08**	**0.00**
H	**1.78**	**0.42**	**4.27**	**0.00**
P/S	**1.41**	**0.45**	**3.11**	**0.00**
Carson Canyon	2.17	1.16	1.88	0.06
Decima	**5.40**	**1.34**	**4.05**	**0.00**
El Seco	-16.16	1160.07	-0.01	0.99
O Pequeno	1.16	1.14	1.02	0.31
Playa Nova	2.72	1.11	2.46	0.01
Visibility	**0.00**	**0.00**	**3.93**	**0.00**
Sea State	**-0.38**	**0.14**	**-2.70**	**0.01**

(B)

Northern bottlenose whale presence	**df**	**AIC**	**ΔAIC**
~ 1 (Null)	224	425.4	196.48
~ Vessel.Activity:Fishing.Area + Vessel.Activity + Fishing.Area + Cloud+ SEA+VIS + Daylight	14	244.8	15.88
~ Vessel.Activity + Fishing.Area + Cloud+ SEA+VIS + Daylight	11	234.35	5.43
~ Vessel.Activity + Fishing.Area + Cloud+VIS + Daylight	10	232.4	3.48
~ Vessel.Activity + Fishing.Area + Cloud + Daylight	**9**	**230.71**	**1.79**
~ Vessel.Activity + Fishing.Area + Cloud	**8**	**228.92**	**0**

Northern bottlenose whale presence ~ Vessel.Activity + Fishing.Area + Cloud Cover				
Coefficient Terms	Estimates	std error	Statistic	p value
T (Intercept)	**-3.89**	**1.12**	**-3.47**	**0.00**
H	**2.02**	**0.42**	**4.77**	**0.00**
P/S	**1.16**	**0.45**	**2.57**	**0.01**
Carson Canyon	0.17	1.28	0.13	0.89
Decima	**2.41**	**1.18**	**2.05**	**0.04**
El Seco	-16.39	1180.08	-0.01	0.99
O Pequeno	2.04	1.11	1.83	0.07
Playa Nova	**2.22**	**1.07**	**2.08**	**0.04**
Cloud Cover	**-0.01**	**0.00**	**-2.05**	**0.04**

Supplementary Data

Table S1. Summary of sperm whale photo id data, showing date, haul number, time, fishing area, trawler activity and speed for each encounter. Trawler activity codes: (H) Hauling (P/S) Preparing/Shooting (T) Towing

Name	ID features	Date	Haul #	Time	Fishing Area	Activity	Associates	Distance between encounters (km)
SPARROW	scar behind dorsal fin, two little scars close to the blow hole and fluke	7/8/2007	44	17:00	Playa Nueva	H	BREIXO, SCRATCHY	**-**
		10/8/2007	48	10:45	Playa Nueva	H	NEBOA, BREIXO	**5**
		14/08/2007	55	9:00	Playa Nueva	H	SCRATCHY	**9**
		15/08/2007	58	19:30	Playa Nueva	H		**58**
		11/9/2007	125	18:00	Playa Nueva	P/S		**16**
SCRATCHY	scratch in left lateral	7/8/2007	44	17:00	Playa Nueva	H	SPARROW, BREIXO	**-**
		14/08/2007	55	9:00	Playa Nueva	H	SPARROW	**4**
BREIXO	right lateral scar, snout scar and fluke	7/8/2007	44	17:00	Playa Nueva	H	SPARROW, SCRATCHY	**-**
		10/8/2007	48	10:45	Playa Nueva	H	NEBOA, SPARROW	**5**
		14/08/2007	56	9:45	Playa Nueva	P/S		**7**
		14/08/2007	56	11:00	Playa Nueva	T	NEBOA	**13**
		27/08/2007	86	10:15	Carson Canyon	P/S	FANECA, IBO	**235**
NEBOA	scars in both laterals and fluke	8/8/2007	45	18:15	Playa Nueva	H		**-**
		8/8/2007	46	20:15	Playa Nueva	T		**8**
		10/8/2007	48	10:45	Playa Nueva	H	BREIXO, SPARROW	**113**
		10/8/2007	49	22:00	Playa Nueva	H		**1**

		13/08/2007	54	18:15	Playa Nueva	T		**57**
		14/08/2007	56	11:00	Playa Nueva	T	BREIXO	**50**
		14/08/2007	56	18:15	Playa Nueva	T		**36**
		14/08/2007	56	21:00	Playa Nueva	H		**12**
FANECA	left lateral scar, fluke	27/08/2007	86	10:15	Carson Canyon	P/S	BREIXO, IBO	**-**
		28/08/2007	88	21:05	Carson Canyon	H		**59**
		29/08/2007	90	9:30	Carson Canyon	T		**54**
		29/08/2007	90	14:45	Carson Canyon	T		**31**
		29/08/2007	91	21:15	Carson Canyon	T		**5**
IBO	scar in dorsal fin and three little depressions in the surface of the head	27/08/2007	86	10:15	Carson Canyon	P/S	FANECA, BREIXO	**-**
		9/9/2007	121	16:30	Playa Nueva	H		**276**
MARMU	fluke	8/8/2007	45	13:23	Playa Nueva	T		**-**
TOR	scar in blow hole	29/07/2007	25	11:10	Playa Nueva	H		**-**
NAT	fluke	28/07/2007	23	10:44	Playa Nueva	H		**-**
NOAH	scar in left lateral and fluke	29/08/2007	91	21:15	Carson Canyon	T	FANECA	**-**

Figure S1. Associations between identified sperm whales. The arrows show the presence of both individuals together near the vessel, and the number of times the whales were seen together. *Breixo* (middle) was seen with all the other animals**.**

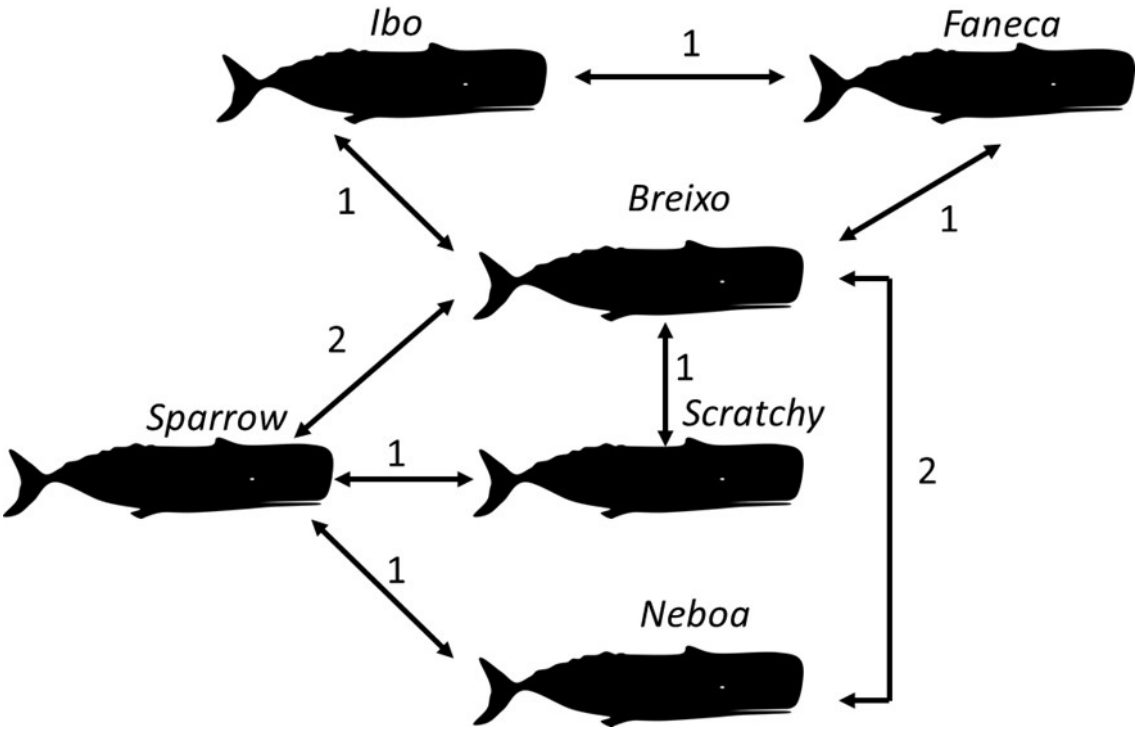
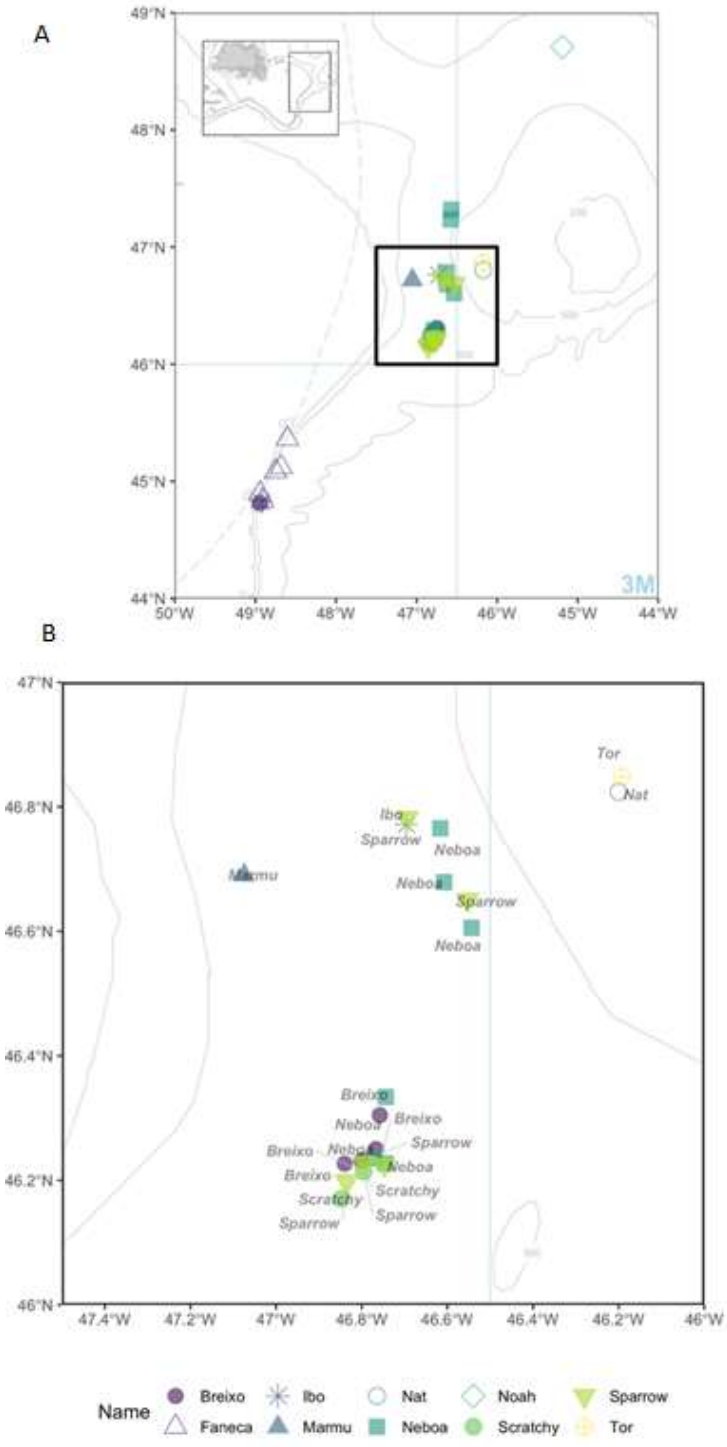
Figure S2. Location of sightings of individual sperm whales in (A) the entire study area and **(B)** an inset of concentrated sightings in the Flemish Pass.