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Marine mammal observations during geophysical surveys from 1995–2020

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Summary

Data from 1,940 geophysical surveys in UK and adjacent waters between 1995 and 2020 were examined to assess the effects of geophysical operations on marine mammals. Over 345,000 hours were recorded as monitoring for marine mammals (over 283,000 hours visual monitoring and over 62,000 hours acoustic monitoring), with acoustic sources being active for 49% of this time. Acoustic sources included airguns and high-resolution sources such as sub-bottom profilers.

A total of 13,686 sightings or acoustic detections comprising a minimum of 154,869 individual animals were encountered. The most frequently encountered identified species was the white-beaked dolphin, followed by the minke whale. Atlantic white-sided dolphins, long-finned pilot whales and harbour porpoises were also encountered frequently, with sperm whales, killer whales and fin whales encountered moderately often and lower numbers of encounters with grey seals, common dolphins, and bottlenose dolphins. Other species were encountered infrequently. The distribution of encounters reflected survey effort and known species distribution, but a decline in sightings of fin whales, sperm whales and Atlantic white-sided dolphins to the West of Shetland after 2005 was unexplained.

When 'large arrays' of airguns (greater than 1,200 cu.in.) were firing there was a significant response (lateral displacement, more localised avoidance, or changes in behaviour) for the grey seal, minke whale, harbour porpoise and all delphinids that were able to be tested except Risso's dolphin. Most of these species showed lateral displacement beyond the range of visual / acoustic detection, although bottlenose dolphins showed fewer displacement and long-finned pilot whales showed only localised avoidance. For harbour porpoises, as well as a decline in detections when the source was active during surveys, there was also a decline in detections after surveys commenced regardless of source activity. Changes in behaviour in various species or species groups included avoidance / travel away from the vessel, reduced interactions with / travel towards the vessel or its equipment, increased swimming speed, surfacing more often and more surface-active behaviours (e.g. breaching, jumping, splashing, spy-hopping). Cetaceans were feeding less often when the source was active. Long-finned pilot whales showed some different responses to source activity compared to other species, with slow swimming and diving recorded more often when the source was active. No responses of any kind were observed in sperm whales, beaked whales, Risso's dolphins or individual mysticete species (other than minke whale) in response to activity of large arrays of airguns, although sample sizes for some species (e.g. beaked whales) were low.

When 'small arrays' of airguns (≤ 1,200 cubic inch) were active there was lateral displacement of minke whales, sperm whales and harbour porpoises beyond the range of visual / acoustic detection. Some species or species groups showed reduced interactions with / travel towards the vessel or its equipment and more surface-active behaviours.

Responses to high resolution sources were able to be examined for the first time, although data were limited. Species had to be combined to increase sample sizes and only pingers and chirps were able to be examined. Nevertheless, for the combined group of all cetaceans, detection rates were reduced when pingers were active and animals remained further from the source when chirps were active. Both responses indicate some degree of lateral displacement. Further data are needed to examine responses of marine mammals to high resolution sources in more detail, but these preliminary results confirm that mitigation should continue to be applied on high resolution surveys.

Responses of marine mammals to the soft start of airguns were examined. All species tested for large arrays (grey seal, minke whale, sperm whale, long-finned pilot whale, killer whale, bottlenose dolphin, white-beaked dolphin, Atlantic white-sided dolphin, and harbour

porpoise) had lower detection rates during the soft start than when the airguns were not active. Of those animals that were detected during the soft start of large arrays, the harbour porpoise was the only species that was found further from the airguns than when they were not active. Some behavioural responses were also evident during the soft start (e.g. avoidance / travel away from the vessel, alterations of course, fast swimming, diving, reduced interactions with / travel towards the vessel or its equipment) and startle responses were also observed on some occasions. Porpoising was more prevalent during the soft start than at any other time on surveys with large arrays of airguns. However, although there was evidence of some avoidance during the soft start, not all individuals did exhibit avoidance. Those mysticetes and delphinids that were present tended to become closer to the source during the soft start before ultimately being further away than they were initially, most likely due to movement of the vessel.

There were more limited data for examining the response of marine mammals to soft starts of small arrays of airguns. Nevertheless, the combined groups of all cetaceans and all delphinids were found to have lower detection rates during the soft start than when the airguns were not active. Of those delphinids that were present during the soft start of small arrays, more were likely to be breaching / jumping than at other times.

This report represents the longest-term analysis of MMO data to date. Although the data can only be used to examine short-term responses, MMO and PAM data are nevertheless a valuable resource for investigating the potential impacts of industrial activities on marine mammals and the effectiveness of mitigation measures.

Contents

1 Introduction

Anthropogenic noise in the world's oceans, and its potential impacts on marine mammals and other marine fauna, has attracted much attention in recent years. Potential impacts of noise on marine mammals include behavioural changes, masking of biologically important sounds and, if received levels are high enough, injury (Richardson *et al.* 1995). Impulsive noise, such as that produced during geophysical surveys, poses a higher risk of auditory injury to marine mammals than non-pulsed noise, due to the high peak levels and rapid rise time that characterise impulsive sounds (Southall *et al.* 2007).

To reduce the risk to marine mammals, some countries have introduced mitigation measures that typically include monitoring by Marine Mammal Observers (MMOs) and/or Passive Acoustic Monitoring (PAM). In the UK, the Joint Nature Conservation Committee (JNCC) first introduced guidelines for seismic surveys, where the sound from airguns is used to explore the sea floor in the search for oil and gas reserves, in 1995. The guidelines initially only covered cetaceans, but in 1998 were extended to cover all marine mammals. There have been several subsequent revisions, with the latest version in 2017 being extended to include all types of geophysical survey, thus including the use of acoustic sources such as sub-bottom profilers in addition to airguns (JNCC Guidelines for Minimising the Risk of Injury to Marine Mammals from Geophysical Surveys; JNCC 2017). The JNCC guidelines have various provisions, including the requirement to monitor for marine mammals prior to commencing acoustic activity and delay the start of the activity if a marine mammal is detected within a specified mitigation zone. Monitoring may be visual (e.g. in daylight) by MMOs or acoustic (e.g. at night or in poor visibility) by PAM operators. When it is clear to start, acoustic activity must commence with a soft start, where power is gradually built up over a period to protect any undetected animals that may be close by. The primary role of the MMO or PAM operator is to provide advice to enable the crew to comply with the JNCC guidelines and hence mitigate potential negative impacts of geophysical operations on marine mammals. MMOs and PAM operators also record data on the operations, the watches and any marine mammals detected using standardised Marine Mammal Recording Forms (JNCC 2012a).

Studies on the impact of geophysical surveys on marine mammals to date have focussed on seismic surveys. These studies include experiments with captive animals exposed to the sound of a seismic airgun (e.g. Lucke *et al.* 2009; Finneran *et al.* 2015), controlled exposure experiments with wild animals (e.g. Miller *et al.* 2009; Dunlop *et al.* 2013, 2015, 2016a, 2016b, 2017, 2018; van Beest *et al.* 2018; Heide-Jørgensen *et al.* 2021), academic studies conducted alongside commercial operations (e.g. Thompson *et al.* 2013a, 2013b; Cerchio *et al.* 2014; Pirotta *et al.* 2014; Winsor *et al.* 2017; Sarnocińska *et al.* 2020; Fernandez-Betelu *et al.* 2021) and predictive modelling (e.g. Zeddies *et al.* 2015; Hückstädt *et al.* 2020). As many geophysical surveys worldwide utilise MMOs (and sometimes PAM), MMO data recorded on the source vessel during operations represents a significant additional resource. Although the primary role of the MMO and PAM operator is mitigation and the data collated are limited spatially and temporally to the locations and durations of surveys, the use of MMO data to examine responses of marine mammals to operations and to assess the effectiveness of mitigation measures is encouraged (National Research Council 2005; Nowacek *et al.* 2013; Nowacek & Southall 2016; Bröker 2019). MMO data from single seismic surveys have been used in some studies (e.g. Weir 2008a; Lalas & McConnell 2016; Vilela *et al.* 2016). Pooling data from multiple surveys to increase sample size is beneficial and has been done previously for seismic surveys in UK waters (Stone 1997, 1998, 2000, 2001, 2003a, 2003b, 2006, 2015a; Stone & Tasker 2006; Stone *et al.* 2017). Similar analyses have been conducted with MMO data from seismic surveys in the Gulf of Mexico, New Zealand, West Africa, Australia, and Ireland (Barkaszi *et al.* 2012; Childerhouse *et al.* 2016; Barkaszi & Kelly 2019; Kavanagh *et al.* 2019; Milne *et al.* 2019). The current study presents an analysis of MMO and PAM data from UK geophysical surveys over a 25-year period from the introduction of the JNCC guidelines in 1995 until 2020. This represents the longest-term study of MMO data to date. In addition to seismic surveys, for the first-time it includes data from high resolution surveys using equipment such as sub-bottom profilers.

2 Methods

2.1 Marine mammal observations and effort

Marine mammal observations were undertaken from geophysical surveys operating in UK waters. Some MMOs also voluntarily submitted their records from surveys operating in the waters of neighbouring countries (Norway, Ireland, Faroes, the Netherlands, Denmark, Germany, and France), although these formed a minority of records. This report examines all data since the introduction of the JNCC guidelines in 1995 until 2020.

Visual watches for marine mammals were carried out during daylight hours. Observers ranged from biologists experienced in marine mammal surveys to non-scientific personnel who in many cases had undergone JNCC-recognised MMO training (https://jncc.gov.uk/our-work/marine-mammal-observer-training/). In addition, PAM was utilised on some surveys during night-time operations and sometimes also during the day. In 1995 sightings were recorded using a non-standard format. Since 1996, MMOs and PAM operators have completed standard marine mammal recording forms that also require that effort (number of hours of visual or acoustic monitoring) is recorded. Several versions of these forms have been issued over the years (latest version JNCC 2012a), but all versions are compatible and allowed data to be included in the database. There are currently four tabs within this form:

- Cover Page: general information about the survey.
- Operations: times of acoustic operations and associated mitigation.
- Effort: details of visual and acoustic monitoring, including time, position, source activity and weather conditions.
- Sightings: details of any marine mammals encountered.

Weather conditions were recorded in discrete categories on the ‘Effort’ tab:

- sea state was categorised as ‘glassy’ (equivalent to Beaufort sea states of 0–1), ‘slight’ (Beaufort sea states 2–3), ‘choppy’ (Beaufort sea states 4–5) and ‘rough’ (Beaufort sea states ≥ 6).
- swell was categorised as 0–2 m, 2–4 m or greater than 4 m.
- visibility was categorised as less than 1 km, 1–5 km or greater than 5 km.
- sun glare was categorised as ‘none’, ‘weak’, ‘strong’ or ‘variable’ with the direction as ‘forwards’ or ‘behind’.
- precipitation was categorised as ‘none’, ‘light rain’, ‘moderate rain’, ‘heavy rain’ or ‘snow’.

When marine mammals were encountered observers recorded the species (with a supporting description and/or photograph), number of animals, behaviour, closest distance of approach to the acoustic source and the source activity at the time of the encounter. Observers used different methods to estimate the range to animals, but the use of a rangefinder stick (Heinemann 1981) was the most common. Observers recorded any behaviours that were apparent rather than selecting from a set list, although the Guide to Using Marine Mammal Recording Forms (latest version JNCC 2012b) gave examples of behaviours that may be seen. Feeding can be difficult to be sure of, but MMOs are taught during training that behaviours indicative of feeding might include cetaceans being observed with a fish; lunge-feeding in baleen whales; and in dolphins erratic, fast swimming with frequent changes of course and birds diving alongside, etc.

2.2 Data quality control

Only data of acceptable quality were entered into the database and subject to analysis. Data checks were applied consistently following a standard list of over 60 checks (Barton 2012). Examples included: checking that source activity was accurately recorded during observation effort; that acoustic source characteristics corresponded with information within the MMO report; that consecutive positions were credible given the time interval and speed of the vessel; that species identity corresponded with the description and/or photograph; and that there was reasonable confidence that behaviour had been recorded accurately (e.g. not an unusually high proportion of sightings by one observer exhibiting the same behaviour). Any errors found were corrected where possible. Only data considered accurate or that had minor inaccuracies that could be corrected were entered into the database. Data with key information missing or errors that were not able to be corrected were discarded.

Following the quality control process, data from a total of 1,940 surveys were included in the database and available for analysis, spanning the period from 1995 to 2020. Of the surveys in the database, 92% were entirely in UK waters, 4% spanned both UK and adjacent waters and 4% were only in adjacent waters of neighbouring countries.

2.3 Acoustic sources

The 1,940 geophysical surveys entered into the database encompass a range of survey types using airguns and/or high-resolution sources. Of these, 1,717 surveys used airguns, with a wide range of array sizes. The smallest airgun array volume was 4 cu.in. (on some site surveys), while the largest was 10,170 cu.in. (on a 2D survey). Very large volumes of airguns were rare, with only nine surveys using volumes exceeding 6,000 cu.in. Site surveys and VSPs used arrays with low numbers of airguns and typically lower total volumes (mostly up to 180 cu.in. for site surveys and between 500 and 1,000 cu.in. for VSPs). 2D, 3D, 4D and OBS surveys had arrays with greater numbers of airguns and larger total volumes (often over 3,000 cu.in.).

The amplitude of sound produced by airgun arrays is influenced more by the number of airguns in an array than the volume (Landrø & Amundsen 2018). Volume of airguns was more often recorded than the number, but where both were recorded there was a correlation between the two. For arrays of up to 1,200 cu.in. the maximum number of airguns recorded was eight, while for larger volume arrays numbers of airguns were typically between 20 and 40. Therefore the volume could be used as a proxy for the number of airguns and, where appropriate, surveys with airguns of small volumes were analysed separately from those with larger airgun volumes. In the context of this report, 'small arrays' refers to arrays with a volume of 1,200 cu.in. or less and 'large arrays' refers to arrays with a volume of more than 1,200 cu.in. Surveys were assigned to each category based on the reported airgun volume, but where airgun volume was not recorded for individual surveys 2D, 3D, 4D and OBS surveys were assigned to the large arrays category and site surveys and VSPs were assigned to the small arrays category, as many of these types of surveys consistently used airgun volumes in the respective category. The small arrays category included 1,123 surveys, while 596 surveys used large arrays (two surveys used both small and large arrays at different times).

Since 2009, the frequency and source level of airgun arrays have been amongst the information requested on the recording forms. From available information, arrays used on 2D, 3D, 4D and OBS surveys typically produced frequencies predominantly up to around 200 Hz, with source levels of around 262 $dB^{pk\text{-}pk}$ re. 1 μPa @ 1 m. Arrays used on site surveys and some VSP operations typically produced frequencies predominantly up to around 250 Hz, with source levels of around 242 $dB^{pk\text{-}pk}$ re. 1 μPa @ 1 m.

There were 265 high resolution surveys utilising a variety of other sources (sometimes in addition to airguns), including sub-bottom profilers (boomers, pingers, sparkers and chirp systems), side-scan sonars and single beam and multibeam echo sounders. Pingers, chirps and sparkers were the most frequently used sources for which data were recorded. Frequencies and source levels were often not recorded, but where noted, frequencies were 3.5 kHz, 1–10 kHz and 50 Hz–4 kHz for pingers, chirps and sparkers respectively and source levels were around 224 dB^{pk-pk} re. 1 µPa @ 1 m, 212–215 dB^{pk-pk} re. 1 µPa @ 1 m and 213–222 dB^{pk-pk} re. 1 µPa @ 1 m respectively. High resolution surveys were included in the JNCC guidelines in 2017 but some consents required mitigation prior to this; most data from high resolution surveys were from 2014 onwards.

2.4 Analysis and statistical tests

For some analyses it was not appropriate to use all the data in the database. For example, some sightings or acoustic detections had no accompanying effort data so could not be used where detection rates per unit effort were calculated; for some other aspects of analysis, effort data was not necessary, and all sightings and acoustic detections were used. When considering biological responses of marine mammals to acoustic source activity, it was appropriate to include the minority of records from waters of neighbouring countries, as these animals belong to the same stocks as those occupying UK waters.

Due to the different characteristics of the various acoustic sources (see section 2.3), different sources were analysed separately. For airguns, large arrays (greater than 1,200 cu.in.) were analysed separately from surveys with small arrays (≤ 1,200 cu.in.). High resolution sources other than airguns were often used in combination; to identify responses to any particular source the analysis for high resolution sources only used data where sources were used singly. The methods used were the same regardless of source type, so the following sections outlining methodology apply to all source types.

For some analyses, other variables had the potential to influence the results. Weather conditions influence the ability of observers to detect marine mammals (e.g. Northridge *et al.* 1995; Teilmann 2003; Hammond *et al.* 2013). If weather was likely to bias the results, periods with the same weather conditions were compared where possible, or otherwise only periods of good observation conditions (i.e. 'glassy' or 'slight' sea states, swell less than 2 m and, for visual observations, visibility greater than 5 km) were used. Location, season, observer ability and monitoring method (visual or acoustic) also needed to be considered as potential influences for some analyses.

Non-parametric statistical tests were used throughout (Siegel & Castellan 1988); these tests make fewer assumptions about the nature of the populations from which the data are drawn and do not require that the data are normally distributed. The following sections describe the tests that were used for each aspect of the analysis.

Results are presented for individual species where sample size permitted. Where the species level sample size was too small, (this varied depending on the test being used), groups of combined species were used (e.g. all seals, all cetaceans, all mysticetes, all beaked whales or all delphinids). These combined species groups comprised all identified and unidentified animals within that taxonomic grouping (Table 1), for example, the mysticetes group included both fin whales and unidentified fin / sei whales, amongst other species. Combined species groups were more often used for high resolution sources and small arrays of airguns as surveys using these sources were often of short duration so sample sizes were lower. For surveys with large arrays of airguns, sample sizes were mostly greater, but beaked whales were combined due to low numbers of detections of individual species.

Table 1. Division of cetacean species into combined species groups for analysis (combined species groups also included unidentified animals within that group).

Mysticetes	Beaked whales	Delphinids
North Atlantic right whale	Northern bottlenose whale	Long-finned pilot whale
Humpback whale	Sowerby's beaked whale	Killer whale
Blue whale		False killer whale
Fin whale		Risso's dolphin
Sei whale		Bottlenose dolphin
Minke whale		White-beaked dolphin
		Atlantic white-sided dolphin
		Common dolphin
		Striped dolphin

2.4.1 General trends in survey effort and species distribution

Maps of effort and species distribution were plotted using DMAP for Windows with the geographic areas referred to throughout the text shown in Figure 1. Maps show the 200 m (short, dashed line) and 1,000 m (long dashed line) isobaths. Effort maps were plotted using data since 1996, when effort was first recorded. As the early effort data did not always record positions in sufficient detail to calculate effort per block, effort maps were plotted after summing the amount of effort in each quadrant where the watch started (1° latitude and longitude rectangle, comprising 30 licensing blocks). Individual species maps are included in Appendix 1. For rarer species (North Atlantic right whale, Sowerby's beaked whale, false killer whale, porbeagle, sunfish and turtles) locations of sightings were plotted. All other species maps were plotted after summing the number of individuals of each species in each offshore oil and gas licensing block (10' latitude x 12' longitude).

All sightings and acoustic detections were included on species maps, but for the more frequently encountered species, sighting rates in different areas over five-year periods were calculated using only sightings that had accompanying effort data. To reduce bias, sighting rates for each five-year period were calculated using only visual data from months of peak occurrence of animals (June to September) and when sources were not active during good observation conditions ('glassy' or 'slight' sea states, swell less than 2 and visibility greater than 5 km). Only areas with survey effort during all five-year periods were included in this comparison.

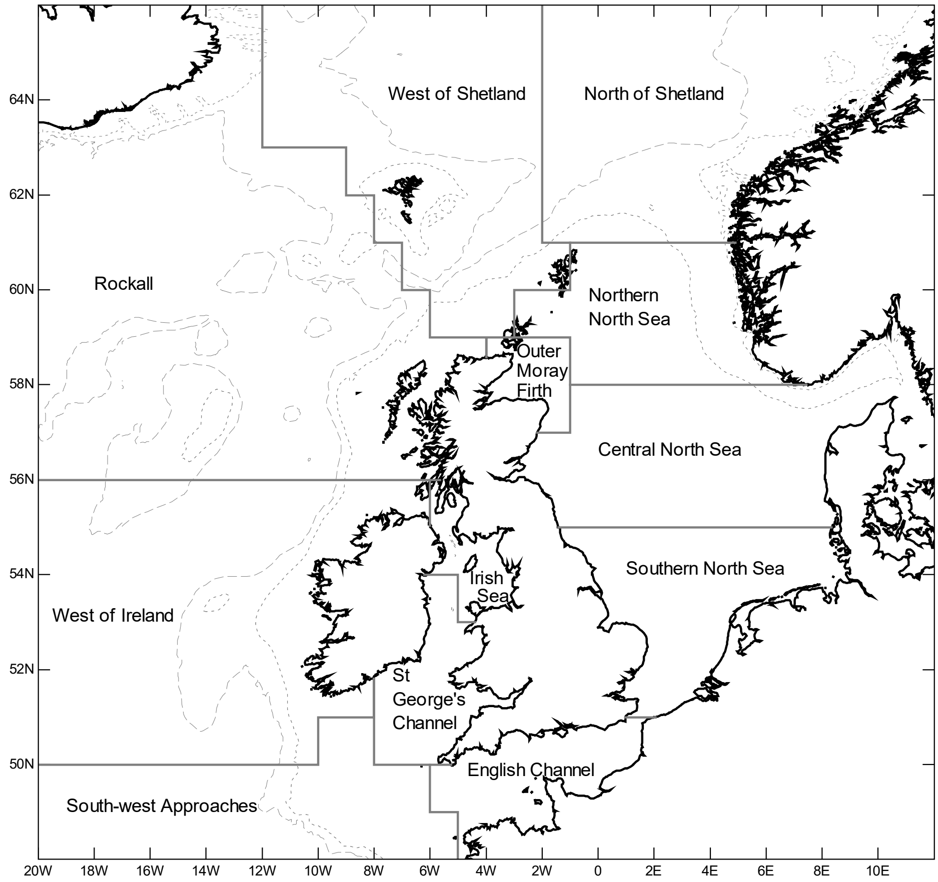


Figure 1. Geographic areas used in data analysis (short, dashed line = 200 m isobath; long dashed line = 1,000 m isobath).

2.4.2 Detection rates (active source versus not active)

Only sightings or acoustic detections that had accompanying effort data were used to calculate detection rates. As there was no distinction between effort during the soft start and that at full power prior to 2009, the source was regarded as active whether it was at full power, undertaking a soft start, or at reduced power for some reason other than a soft start. Most effort when active would have been at full power, as the soft start and other reduced power operations are of relatively short duration. Only data where one type of source was recorded as being active were used. For airguns, surveys with large arrays were analysed separately from those with small arrays. High resolution sources were analysed separately; sample sizes were only sufficient to analyse data for pingers and chirps.

Detection rates may be influenced by other variables (e.g. location, season, weather, monitoring method and observer ability). Therefore matched pairs (active versus not active) were used where for each pair, the survey, ship, month, observer / PAM operator, monitoring method (visual or acoustic) and weather conditions (sea state, swell and, for visual observations, visibility; where recorded also wind force, sun glare and precipitation) were the same, so the only remaining variable was the source activity (controlling for survey also controlled to some extent for location as each survey was conducted within a limited area).

The resulting matched pairs (active versus not active) were tested using the Wilcoxon signed ranks test, a non-parametric test appropriate for two related or matched samples that ranks the differences between each pair. It compares both the direction of the difference in each pair (i.e. which is greater) and also the magnitude of the difference (i.e. by how much is it greater). The Wilcoxon signed ranks test can be performed on small samples, with significant results being able to be detected with sample sizes as low as five matched pairs (Siegel & Castellan 1988). For larger samples, the test statistic T^+ is approximately normally distributed so in these cases z was calculated and its associated probability was determined by reference to tables for the normal distribution.

2.4.3 Detection rates prior to and post operations commencing

Monitoring often commenced in the days prior to operations commencing, as preparations were made (e.g. gear being deployed). Detection rates in the week prior to operations commencing were compared to detection rates in the week after operations commencing. Due to the low number of marine mammal detections during high resolution surveys, sufficient data were only available for analysis of surveys using airguns.

Matched pairs (week before versus week after operations commenced) were used where for each pair the survey, ship, observer / PAM operator, monitoring method (visual or acoustic) and weather conditions (sea state, swell and, for visual observations, visibility; where also recorded wind force, sun glare and precipitation) were the same. Temporal and spatial variations were controlled to some extent by having all observations within each matched pair being within a two-week window on the same survey. The resulting matched pairs (week before versus week after operations commenced) were tested using the Wilcoxon signed ranks test.

2.4.4 Closest distance of approach to the source (active versus not active)

The closest distance of approach to the source during an encounter was compared between periods when the source was active and periods when it was not active. The source was regarded as active whether it was at full power, undertaking a soft start or at reduced power for some reason other than a soft start. As the closest approach could occur at any point during an encounter, only those encounters where the source was either active or inactive throughout the whole encounter were used. Distance estimation with PAM was not as accurate as with visual monitoring (Stone 2015b, 2022), so only visual detections (with or without accompanying effort data) were used.

Operations were less likely to be conducted in rough weather conditions and in such conditions, animals would be harder to detect at distance; this could result in bias towards closer distances at times when the source was not active. This potential bias was controlled by using only sightings during good observation conditions (sea state ‘glassy’ or ‘slight’, swell < 2m and visibility > 5km). Similarly, the experience of the observer could have introduced bias, as less experienced observers (e.g. non-dedicated MMOs) would be less likely to detect animals at greater distances and such observers were more likely only to observe during the required pre-shooting search (i.e. only when the source was not active); this could also result in bias towards closer distances when the source was not active. To reduce this potential bias only sightings by observers with good detection skills were used. Stone (2015a) found that for experienced observers a minimum of 20% of detections were more than 1 km away and used this as a criterion for selecting observers with good detection skills. The same criterion was applied here, using only observers who had at least 20 sightings to determine those who met this standard. For airguns, surveys with large arrays were analysed separately from those with small arrays. For high resolution sources, sample sizes were only sufficient to analyse data for chirps.

The closest distance of approach of animals to the source was compared (active versus not active) using the Wilcoxon-Mann-Whitney test. Scores were ranked and W_x was determined by summing the ranks in the smallest group. The Wilcoxon-Mann-Whitney test can be performed on small samples, with significant results being able to be detected with sample sizes as low as three in each group (Siegel & Castellan 1988). For larger samples, the distribution of W_x approaches that of the normal distribution and therefore z was calculated in these cases and its associated probability was determined by reference to tables for the normal distribution.

2.4.5 Behaviour

Only visual sightings were used to examine behaviour of marine mammals. All sightings were used, including those without associated effort and during any weather conditions. The frequency of occurrence of each recorded behaviour was compared between periods when the source was active and not active, using only sightings where source activity / inactivity remained the same throughout the encounter. The source was regarded as active whether it was at full power, undertaking a soft start or at reduced power for some reason other than a soft start.

Similar behaviours (e.g. breaching, jumping, somersaulting) were grouped together to avoid any bias due to inter-observer variation in terminology. The chi-squared test was used to compare the observed frequency with the expected frequency had there been no difference between groups (active versus not active). The chi-squared test for two groups requires that expected frequencies in both groups are at least five (Siegel & Castellan 1988). This condition could not be met during high resolution surveys due to the low number of sightings, therefore behaviours could only be analysed for surveys using airguns. As airgun volume was likely to influence the results, surveys with large arrays were analysed separately from those with small arrays. For some behaviours where non-significant trends were found for individual species, combined species groups were used to increase the sample size, thereby increasing the power of the statistical test (Siegel & Castellan 1988).

2.4.6 Effectiveness of the soft start

The data were examined to look for responses of marine mammals to the soft start that might indicate whether it is an effective mitigation measure. Detection rates, the closest distance of approach to the source and behaviour were compared for periods when the source was not active, periods when it was at full power and periods during the soft start. As the soft start is of relatively short duration sample sizes were often low; where individual species were unable to be examined, combinations of species were used.

Matched samples were used to compare detection rates at each source activity level during each month of each survey when monitoring method (visual or acoustic) and observer / PAM operator were the same; only data recorded during good weather conditions (sea state 'glassy' or 'slight', swell < 2m and, for visual observations, visibility > 5km) were used. Comparing samples within surveys controlled to some extent for location. Only surveys where effort during the soft start had been differentiated from effort at full power were used (July 2009 onwards). The results were tested using the Friedman two-way analysis of variance by ranks, a non-parametric equivalent of the analysis of variance. Scores for each matched sample were ranked (1, 2 or 3) and a value for F_r calculated with the associated probability determined with reference to the χ^2 distribution. For significant results, multiple comparisons of pairs of treatments were tested using the Wilcoxon signed ranks test to determine where the significant differences lay, with the resulting p-values adjusted using the Bonferroni correction due to the increased risk of a type 1 error when using multiple comparisons. Due to the low number of marine mammal detections during high resolution surveys, sample sizes were only sufficient to analyse data for surveys using airguns.

The closest distance that marine mammals approached the source during the soft start was compared to the closest distance of approach when the source was not active or was at full power, using the same criteria as described in Section 2.4.4. The Kruskal-Wallis one-way analysis of variance by ranks was used to compare the closest distance of approach at different source activities; for larger samples the Kruskal-Wallis statistic KW is well approximated by the χ^2 distribution thus the associated probability was determined. Where results were significant, multiple comparisons of pairs of treatments were conducted using Dunn's test to determine where the significant differences lay, with the resulting p-values adjusted using the Bonferroni correction. Due to low numbers of sightings during the soft start on surveys with small arrays of airguns and high-resolution surveys, the closest distance of approach could only be compared for surveys with large arrays of airguns.

Since July 2009, observers have recorded the first, closest and last distance that animals were observed from the source during the soft start period. These distances were compared to investigate general movement during the soft start in relation to the vessel. Both visual and acoustic detections were used, but animals detected by both means were excluded to ensure that the same method was used to estimate distance throughout each encounter. The three distances for each encounter were ranked (1, 2 or 3) and tested using the Friedman two-way analysis of variance by ranks, with the associated probability determined with reference to the χ^2 distribution. For significant results, multiple comparisons of pairs of treatments were tested using the Wilcoxon signed ranks test to determine where the significant differences lay, with the resulting p-values adjusted using the Bonferroni correction due to the increased risk of a type 1 error when using multiple comparisons. Due to low numbers of encounters during the soft start on surveys with small arrays of airguns and high-resolution surveys, distances throughout the soft start could only be compared for surveys with large arrays of airguns and for combined species groups.

Behaviour was compared using visual sightings where source activity (not active, soft start or full power) did not change during the encounter. All sightings from all years were used, regardless of observer or weather conditions (weather being unlikely to influence the ability of the observer to record behaviour) or whether there was accompanying effort data. The frequency with which different behaviours were exhibited was compared using the chi-squared test, for all behaviours and species where the expected frequency in all groups was at least five. This condition could only be met for surveys with airguns; due to low numbers of sightings during the soft start this condition often could not be met for individual species so combined species groups were also examined.

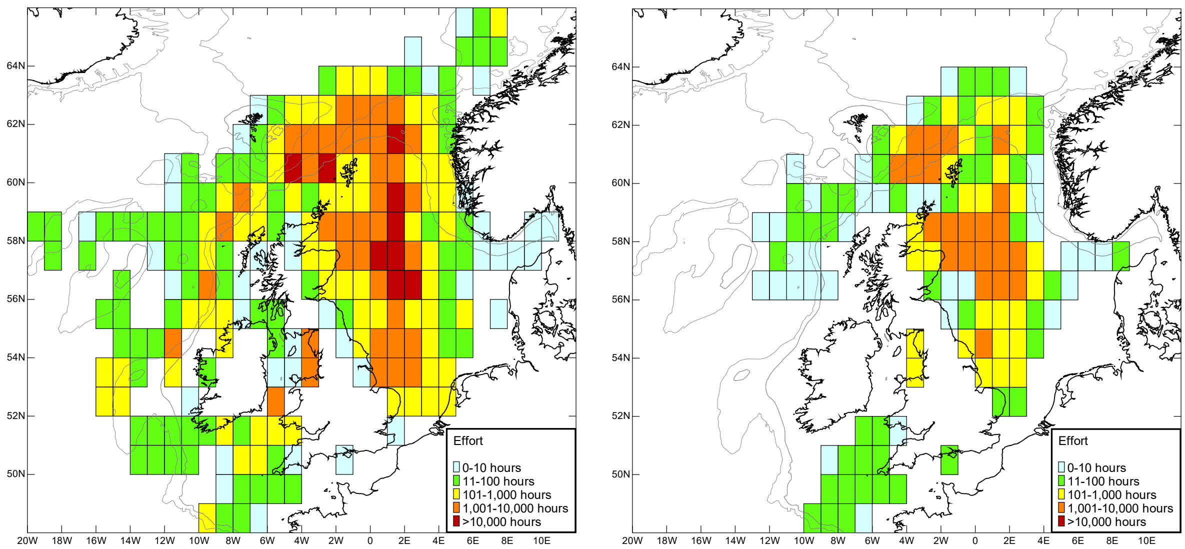
Travel away from the vessel was examined in relation to the distance that marine mammals were from the source. Visual sightings where source activity (not active, soft start or full power) did not change during the encounter were assigned to distance bands using the recorded closest distance of approach. Within each distance band, the frequency of travel away from the vessel was compared for different source activities using the chi-squared test, for all distances and species where the expected frequency in all groups was at least five. This condition could only be met for surveys with large arrays of airguns; due to low numbers of sightings during the soft start at each distance band this condition could only be met for the combined species groups of all cetaceans and all delphinids.

3 Results

3.1 Overview of survey effort and species distribution

Observations encompassed 230 quadrants (1º rectangles = 30 licensing blocks) throughout the UK and some adjacent waters, including some of which were passed in transit to or from the survey location when operations were not ongoing, but sightings were still recorded. A total of 345,376 hours 28 minutes were recorded as monitoring for marine mammals between 1996 and 2020 (effort was not recorded prior to 1996); of this, 283,169 hours 49 minutes were recorded for visual monitoring and 62,206 hours 39 minutes for acoustic monitoring. Acoustic sources were active for 49.1% of the total time spent monitoring.

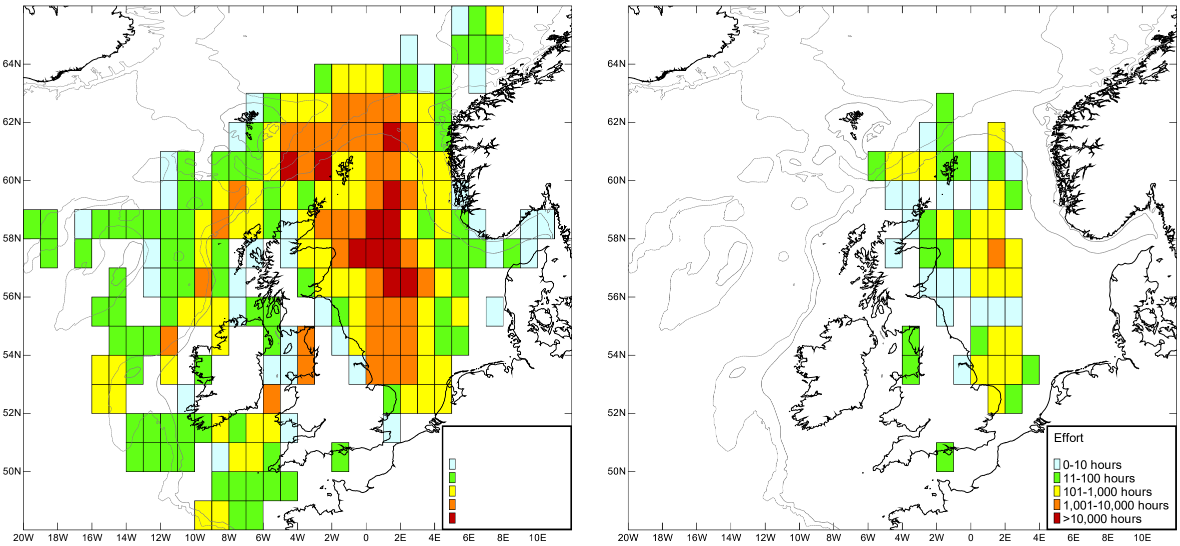
As well as having fewer hours than visual monitoring, acoustic monitoring was more restricted to UK waters (Figure 2). Whilst some monitoring was undertaken while vessels were in transit, which sometimes was from foreign ports, this was more likely to be visual monitoring with PAM being mostly limited to within survey areas. PAM data were not received from the West of Ireland - PAM was not used much prior to 2002 (Stone 2015b) and most reports from surveys West of Ireland were prior to this (Figure 4) (data from Irish waters are routinely submitted to Irish regulators and not to JNCC).



a) Visual monitoring   b) Acoustic monitoring

Figure 2. Visual and acoustic monitoring effort during geophysical surveys, 1996–2020 (scale 1° quadrants = 30 licensing blocks).

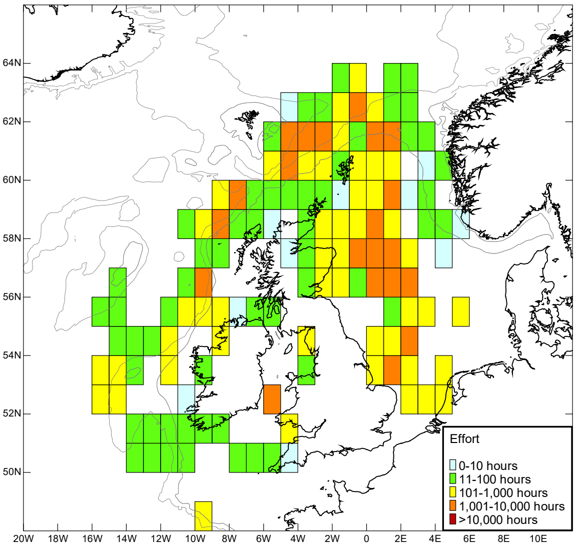
As the JNCC guidelines did not include sources other than airguns until 2017, the hours of monitoring and the area surveyed were greater for seismic surveys than high resolution surveys without airguns; monitoring effort on high resolution surveys was mostly in the North Sea with small amounts in the Irish Sea and English Channel (Figure 3).



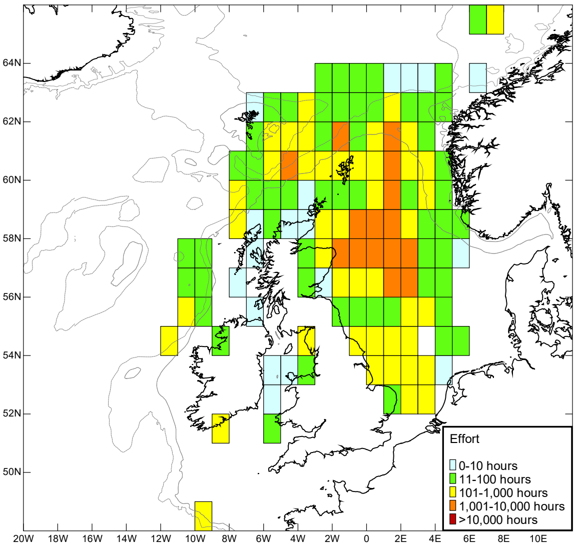
a) Seismic surveys with airguns b) High resolution surveys without airguns

Figure 3. Monitoring effort (visual and PAM combined) during geophysical surveys with and without airguns, 1996–2020.

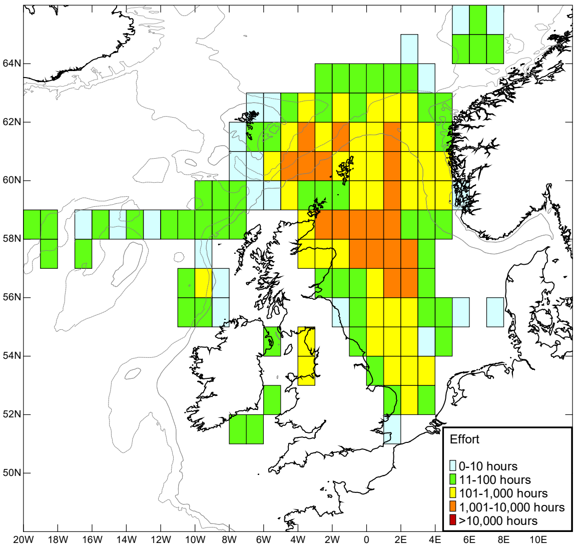
There were temporal variations in monitoring effort, both between years and within years (Figure 4 and Figure 5). Whilst survey effort was high in the North Sea and to the West of Shetland in all years, effort in the Rockall area was higher in earlier years when this area was opened to exploration (in the 16th and 17th licensing rounds); additional survey effort extended to the banks further west of Rockall between 2006 and 2015 (Figure 4). Between 2016 and 2020 there was no survey effort in the Rockall area, but there was more effort in the South-west Approaches. Most effort in deep water areas to the west of Britain and Ireland occurred between April and September when weather conditions are more favourable (Figure 5). The geographical extent of surveys was most restricted between January and March.



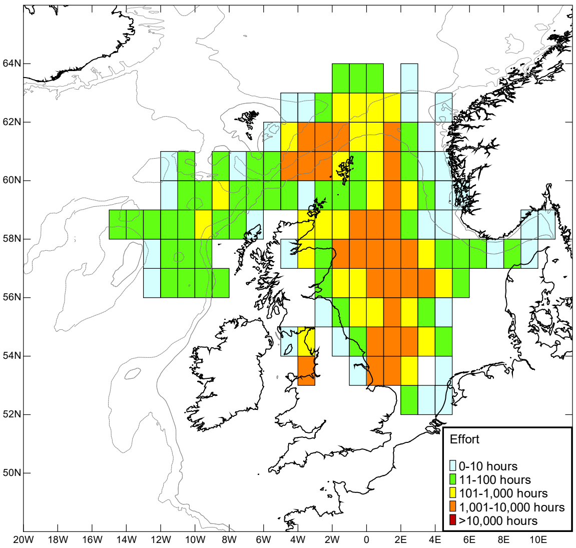
a) 1996–2000



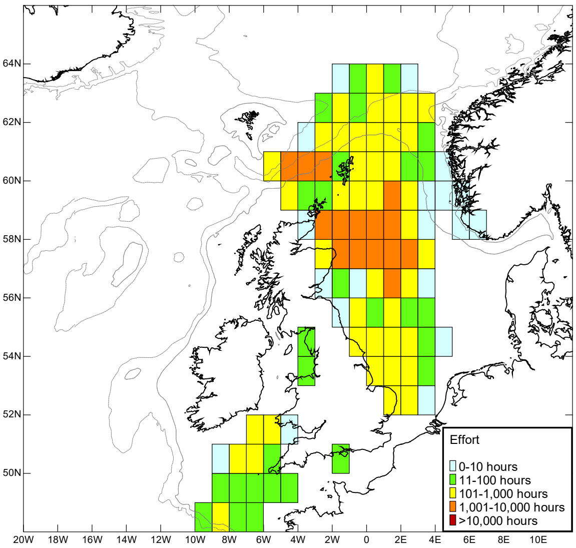
b) 2001–2005



c) 2006–2010

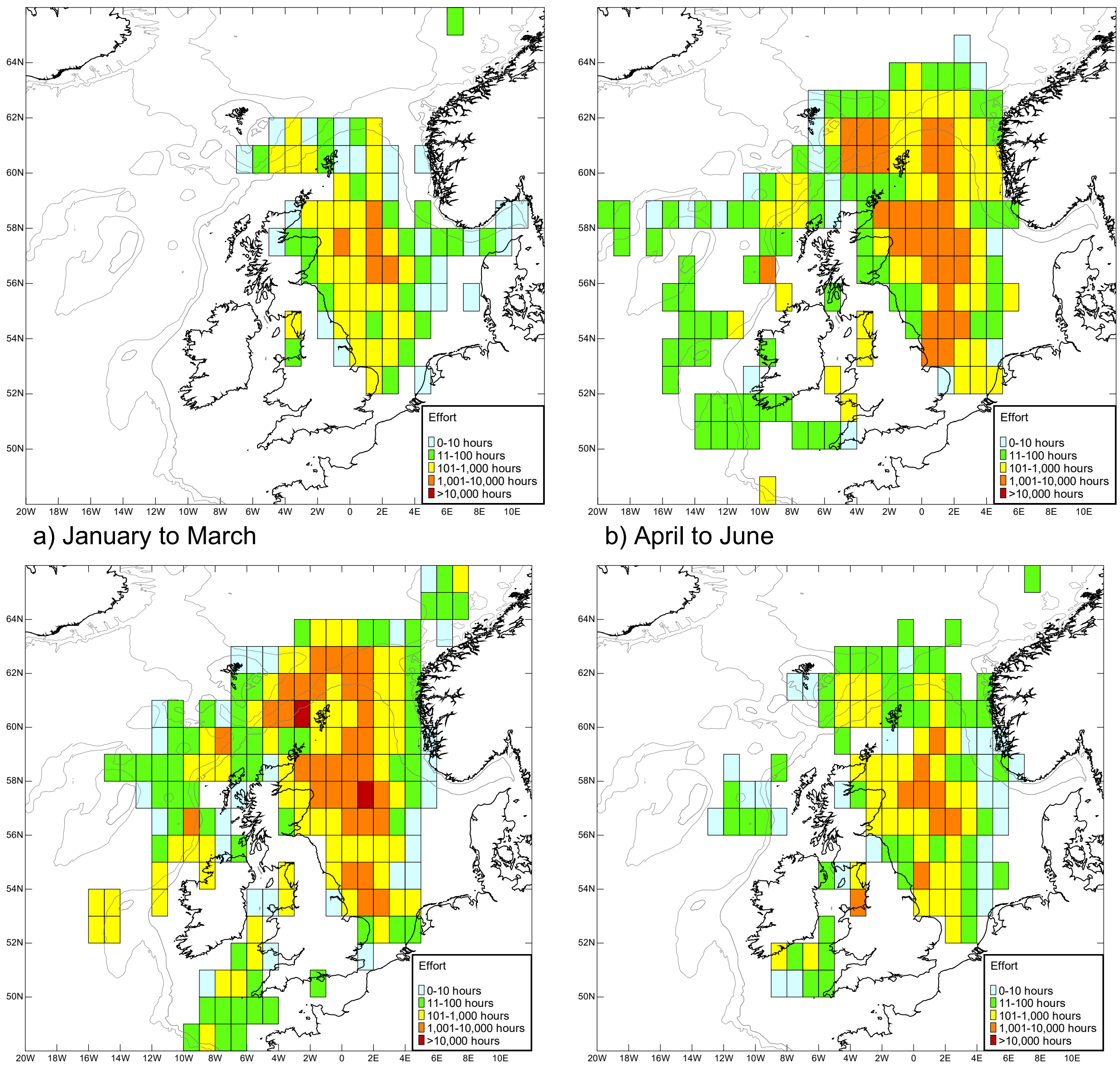


d) 2011–2015



e) 2016–2020

Figure 4. Monitoring effort (visual and PAM combined) during geophysical surveys over five-year periods from 1996–2020.



a) January to March

b) April to June

c) July to September

d) October to December

Figure 5. Seasonal monitoring effort (visual and PAM combined) during geophysical surveys from 1996–2020 (all years combined).

A total of 13,686 sightings or acoustic detections comprising a minimum of 154,869 individual animals were encountered. The most frequently encountered identified species over the 25-year period was the white-beaked dolphin (Table 2), followed by the minke whale (an encounter being one or more animals occurring together). Atlantic white-sided dolphins, long-finned pilot whales and harbour porpoises were also encountered frequently, with sperm whales, killer whales and fin whales encountered moderately often and lower numbers of encounters with grey seals, common dolphins, and bottlenose dolphins. Other species were encountered infrequently. There were 217 mixed species sightings, with the species most often involved in multi-species associations being long-finned pilot whales (104 associations) and Atlantic white-sided dolphins (75 associations). Long-finned pilot whales and Atlantic white-sided dolphins were observed together on 41 occasions. Long-finned pilot whales were also seen in association with unidentified dolphins on 44 occasions but only occasionally with other species. Atlantic white-sided dolphins were also seen with fin whales (8 associations) and white-beaked dolphins (8 associations) and occasionally with other species.

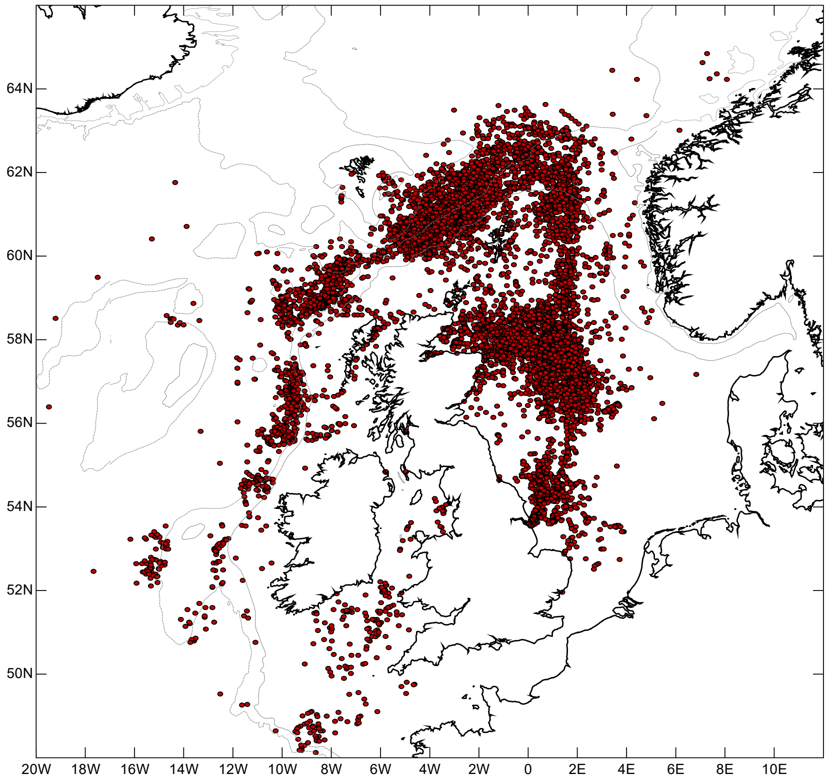
Table 2. Marine mammal encounters during geophysical surveys in UK and adjacent waters from 1995–2020 and estimated number of individuals. Where number of individuals could not be determined with PAM a minimum number of one was assigned; encounters with mixed species groups are listed under each species but are only counted once in the totals for each column.

Species	No. sightings (and no. individuals)	No. acoustic detections (and no. individuals)	No. visual and acoustic detections (and no. individuals)
Seal sp.	294 (380)	-	-
Grey seal	330 (371)	-	-
Harbour seal	46 (52)	-	-
Cetacean sp.	951 (5,770)	96 (107)	9 (129)
Whale sp.	630 (1,356)	4 (4)	1 (80)
Large whale sp.	265 (506)	-	-
North Atlantic right whale (probable)	1 (1)	-	-
Humpback whale	35 (67)	-	1 (1)
Blue whale	14 (15)	-	-
Fin whale	407 (960)	-	-
Sei whale	36 (72)	-	-
Humpback / sperm whale	23 (28)	-	-
Blue / fin / sei whale	28 (74)	-	1 (1)
Fin / sei whale	177 (389)	-	-
Fin / sei / humpback whale	59 (116)	-	-
Fin / sei / blue / humpback whale	323 (765)	-	-
Fin / blue whale	61 (154)	-	-
Sperm whale	481 (723)	157 (168)	21 (37)
Medium whale sp.	109 (163)	-	1 (1)
Minke whale	1,250 (1,492)	2 (2)	1 (2)
Beaked whale sp.	12 (24)	-	-
Northern bottlenose whale	13 (47)	-	-
Minke / northern bottlenose whale	1 (1)	-	-
Sowerby's beaked whale	6 (14)	-	-
Long-finned pilot whale	702(15,022)	19 (19)	35 (1,318)
Killer whale	449 (3,124)	2 (5)	4 (21)
False killer whale	1 (7)	-	-

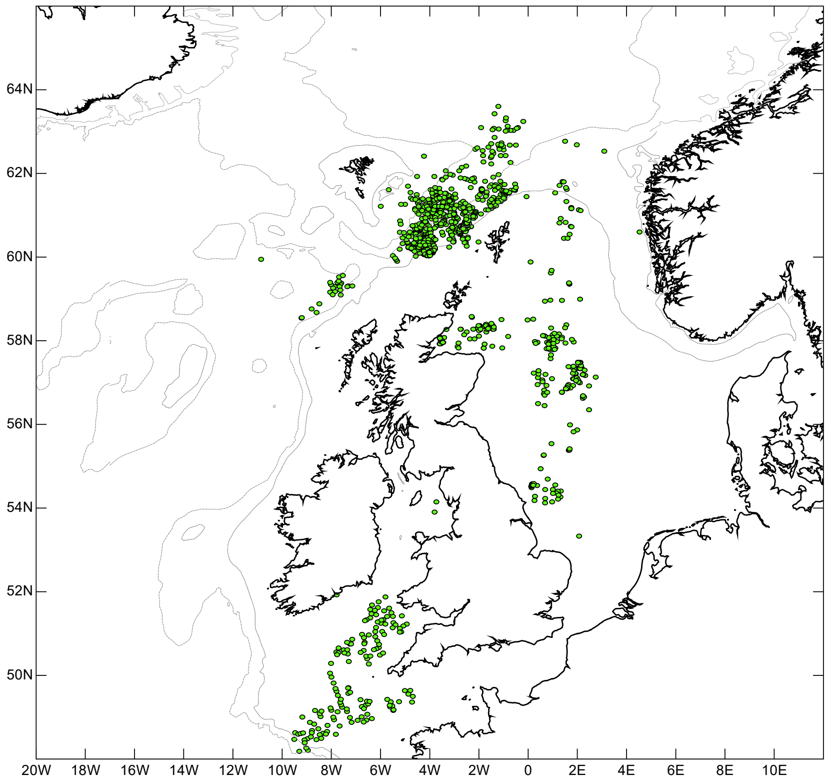
Species	No. sightings (and no. individuals)	No. acoustic detections (and no. individuals)	No. visual and acoustic detections (and no. individuals)
Long-finned pilot / false killer whale	1 (6)	-	1 (1)
False killer whale / killer whale / Risso's dolphin	1 (2)	-	-
Delphinid (dolphin / long-finned pilot / killer / false killer whale)	16 (168)	92 (265)	3 (32)
Dolphin sp.	1,871(24,803)	691 (2,305)	60 (1,346)
Dolphin sp. (not porpoise)	71 (576)	-	1 (4)
Risso's dolphin	93 (753)	-	5 (57)
Bottlenose dolphin	131 (1,550)	-	4 (34)
Risso's / bottlenose dolphin	5 (28)	-	-
White-beaked dolphin	1,524(20,237)	2 (2)	26 (593)
Atlantic white-sided dolphin	749(44,456)	5 (14)	70 (6,863)
Lagenorhynchus sp.	182 (4,282)	-	7 (2,056)
Common dolphin	297 (5,152)	-	17 (670)
Striped dolphin	11 (477)	-	-
Common / striped dolphin	5 (39)	-	-
Common / striped / Atlantic white-sided dolphin	1 (4)	-	-
Common / striped / white-beaked / Atlantic white-sided dolphin	110 (2,325)	-	2 (48)
Common / Atlantic white-sided dolphin	25 (335)	-	1 (150)
Harbour porpoise	620 (1,486)	145 (152)	5 (10)
Total	**12,209(138,372)**	**1,214(3,043)**	**266(13,454)**

In addition to marine mammals there were 34 sightings of basking sharks (37 individuals), 12 of unidentified sharks (14 individuals) and two sightings of individual porbeagles. Five sightings of individual turtles were also recorded, four leatherback and one loggerhead. There was one record of an individual sunfish, although it is likely that more were encountered as most observers would not record sunfish on the recording forms.

The distribution of sightings and acoustic detections reflected survey effort, with most sightings / detections occurring in the Central North Sea and to the West of Shetland (Figure 6). There were also high numbers of sightings / detections in the Northern North Sea and North of Shetland areas. In areas to the west of Britain and Ireland, sightings / detections tended to be clustered along the shelf edge, but effort in these areas was often high around the shelf edge (Figure 2). Compared to effort, there were relatively high numbers of encounters in the St George's Channel, South-west Approaches, and the Rockall Trough, but few in the Irish Sea. The area with least sightings was the English Channel, but survey effort was also lowest in that area.



a) Visual sightings



b) Acoustic detections

Figure 6. Encounters with marine mammals during geophysical surveys, 1995–2020.

Individual species maps are included in Appendix 1 (Figure 12 to Figure 33). Seals were encountered mostly in the North Sea (Figure 12 and Figure 13). Grey seals were seen more often than harbour seals, with numbers being highest in the Southern North Sea. Some seals were also seen to the West of Shetland although grey seals were observed further offshore there than harbour seals. There were a few sightings of grey seals in the Irish Sea and sightings of both species in the North Channel.

Large rorqual whales (humpback, blue, fin and sei whales) were seen mostly in shelf slope and deep waters to the north and west of Britain and Ireland (Figure 14 to Figure 17), with fin whales seen more often than the other large rorquals. There were occasional sightings of fin whales in the North Sea and one sighting of a group of four fin whales in the St George's Channel. Humpback whales were sometimes seen relatively close inshore to the east of Shetland and in 2012 there were two sightings in the Southern North Sea. In addition to the large rorquals, there was one sighting regarded as a probable north Atlantic right whale to the North of Shetland in the year 2000 (Figure 30).

Sperm whales were also found predominantly in deep waters and on the shelf slope to the north and west of Britain and Ireland (Figure 18). There was one acoustic detection as far south as the South-west Approaches and occasional encounters in the North Sea

Like the larger rorqual whales, minke whales were also found along the shelf edge and in deep waters to the north and west of Britain and Ireland but were also widespread in shelf waters of the North Sea (Figure 19). Some were also seen in shelf waters of the South-west Approaches and to the west of Scotland. Minke whales were sometimes seen relatively close inshore in the Outer Moray Firth, around Shetland, in the Minch and on the east coast of Scotland and England.

There were infrequent sightings of beaked whales. Northern bottlenose whales were seen in deep waters from the Rockall Trough to the North of Shetland but with occasional sightings in the Northern North Sea and one individual off Aberdeen in July 2007 (Figure 20). Sowerby's beaked whales were only seen in deep waters to the West of Shetland (Figure 30).

Long-finned pilot whales were distributed along the shelf slope and in deep waters from the North of Shetland to the South-west Approaches, but with most occurring in north-western areas (Figure 21). They were also sometimes encountered in the Northern and Central North Sea, particularly along the Rinne (a channel between 200 m and 500 m depth that lies parallel to the south-western coast of Norway).

Killer whales had a predominantly northern distribution (Figure 22). Although they were encountered in deep waters, including occasionally to the West of Ireland, most encounters were on the outer shelf and shelf edge to the North and West of Shetland, with a concentration of encounters in an area to the north-east of Shetland. There were also scattered encounters in the Rinne and throughout the Northern North Sea. There was one sighting of false killer whales to the west of Ireland (Figure 30).

Of the dolphin species recorded, distribution varied between those found mainly in deeper waters further offshore, those found primarily on the shelf and those with a more wide-ranging distribution. Risso's dolphins, Atlantic white-sided dolphins and striped dolphins were encountered mostly beyond the continental shelf. Risso's dolphins were mostly along the shelf edge to the West of Shetland, with some extending to the North of Shetland (Figure 23). However, there were also scattered sightings in shelf waters in the Central and Northern North Sea, and in the St George's Channel and Irish Sea. Although most Risso's dolphins were seen much further offshore, there were some sightings close inshore on the north-east coast of Scotland and in the Outer Hebrides. Atlantic white-sided dolphins were encountered predominantly in deep waters and at the shelf edge to the West of Shetland, with many also seen to the North of Shetland (Figure 26). Their deep-water distribution extended south to the Rockall Trough and West of Ireland. They were also found in shelf waters of the Central and Northern North Sea and some on the shelf to the west of Scotland. Sightings of striped dolphins were infrequent but were also mostly in deep waters to the West and North of Shetland and to the West of Ireland (Figure 28). There were only two sightings of striped dolphins in the Central and Southern North Sea.

White-beaked dolphins were found predominantly in shelf waters of the Central and Northern North Sea (Figure 25). Their distribution extended further north to the shelf edge to the West and North of Shetland and south to the Southern North Sea. Although some were seen in deep waters, numbers there were lower than on the shelf. As well as being seen frequently in the North Sea, there were some sightings to the west of Scotland.

Bottlenose and common dolphins were more evenly spread between shelf waters and waters further offshore. Bottlenose dolphins were not encountered as often as some other dolphin species, but their distribution was widespread with scattered sightings throughout the North Sea and to the west of Britain and Ireland (Figure 24). Bottlenose dolphins were seen in waters of all depths, from deep waters West and North of Shetland and in the Rockall Trough to inshore sightings in the Moray Firth, Aberdeenshire, Shetland, and the Minch. They were also spread over a range of latitudes, from the North of Shetland to the Southern North Sea and St George’s Channel. Common dolphins were also widespread. They were common to the south-west of Britain, being encountered in high numbers in shelf waters of the St George’s Channel and on the outer continental shelf of the South-west Approaches and in the western part of the English Channel (Figure 27). Their distribution extended north along the shelf edge and deep waters West of Ireland and in the Rockall Trough, and there were also high numbers at the shelf edge to the North and West of Shetland. There were scattered sightings in the Northern and Central North Sea but only occasional sightings in the Southern North Sea. Some sightings occurred relatively close inshore in west Wales, southern Ireland, the north and east coast of Scotland and in the Outer Hebrides.

Harbour porpoises also had a widespread distribution. Most were encountered in the North Sea, throughout southern, central, and northern areas but with concentrations in the Outer Moray Firth (Figure 29). Their distribution was mainly on the shelf but extended into shelf edge and deeper waters to the West and North of Shetland. They were also seen to the west of Britain, mostly in shelf waters. There were several encounters in the Minch and the St George’s Channel, and they were the cetacean seen most often in the Irish Sea.

Sightings of non-mammalian marine fauna reflected survey effort. Basking sharks were seen mostly in the Central and Northern North Sea and to the West of Shetland (Figure 31). Similarly, both porbeagles were seen in the Central North Sea and the single sunfish recorded was West of Shetland (Figure 32). One leatherback turtle was seen in the South-west Approaches, but other turtles were seen in the Central and Northern North Sea and North of Shetland (Figure 33).

Survey effort was unevenly distributed over the years (Figure 4) and the spatial distribution of encounters with most species did not show any clear temporal patterns unrelated to survey effort. However, there were some species where sighting rates in some areas varied between five-year periods to an extent that could not be fully explained by varying effort (Table 3). Fin whales, sperm whales and Atlantic white-sided dolphins were encountered mostly in northern areas, but sighting rates of all three species to the West of Shetland declined markedly after 2005; sighting rates of Atlantic white-sided dolphins also declined over time to a lesser extent to the North of Shetland and in the Northern North Sea. Sighting rates of long-finned pilot whales also declined West of Shetland after 2005 but then increased to their highest level between 2011 and 2015. For some other species there was an increase in sighting rates further south. In the Southern North Sea grey seals were encountered more often in the last 10 years and minke whales were encountered more often in the last 15 years, particularly between 2006 and 2015. Sighting rates of harbour porpoises also increased in the Southern North Sea between 2006 and 2015 but then declined again; sighting rates were low in northern areas around Shetland from 2006 onwards, but sighting rates in the Outer Moray Firth steadily increased over time. Conversely sighting rates of white-beaked dolphins in the Outer Moray Firth declined over time.

Table 3. Sighting rates per 1,000 hours survey effort over five-year periods in different geographical areas (only areas surveyed in all periods are included).

Species	Area	1996 to 2000	2001 to 2005	2006 to 2010	2011 to 2015	2016 to 2020
Grey seal	West of Shetland	0.00	1.10	0.00	0.00	0.00
	North of Shetland	0.00	0.00	0.00	0.00	0.00
	Northern North Sea	0.00	0.73	2.13	0.00	2.92
	Outer Moray Firth	0.00	0.00	11.18	10.51	5.59
	Central North Sea	1.69	0.38	0.45	0.27	5.86
	Southern North Sea	0.00	0.00	0.00	49.56	44.06
Fin whale	West of Shetland	25.97	17.63	1.77	1.99	2.32
	North of Shetland	7.32	0.00	0.00	2.60	2.96
	Northern North Sea	0.00	0.00	0.00	0.00	0.00
	Outer Moray Firth	0.00	0.00	0.00	0.00	0.00
	Central North Sea	0.00	0.00	0.00	0.00	0.00
	Southern North Sea	0.00	0.00	0.00	0.00	0.00
Sperm whale	West of Shetland	24.11	15.42	2.95	4.64	5.81
	North of Shetland	3.66	0.00	2.17	1.30	2.96
	Northern North Sea	0.00	0.00	0.00	0.00	0.00
	Outer Moray Firth	0.00	0.00	0.00	0.00	0.00
	Central North Sea	0.85	0.00	0.00	0.00	0.00
	Southern North Sea	0.00	0.00	0.00	0.00	0.00
Minke whale	West of Shetland	5.56	12.12	2.95	13.24	4.64
	North of Shetland	4.88	14.48	7.22	5.21	11.85
	Northern North Sea	5.77	8.36	10.21	3.68	4.38
	Outer Moray Firth	10.52	9.46	13.42	15.76	1.86
	Central North Sea	6.77	14.27	5.90	16.20	10.98
	Southern North Sea	0.00	1.83	21.42	50.80	7.34

Species	Area	1996 to 2000	2001 to 2005	2006 to 2010	2011 to 2015	2016 to 2020
Long-finned pilot whale	West of Shetland	7.42	6.61	1.18	13.24	4.64
	North of Shetland	6.10	0.00	0.72	1.30	0.00
	Northern North Sea	0.00	0.00	0.00	0.61	1.46
	Outer Moray Firth	0.00	0.00	0.00	0.00	0.00
	Central North Sea	0.00	0.00	0.00	0.00	0.00
	Southern North Sea	0.00	0.00	0.00	0.00	0.00
Killer whale	West of Shetland	0.00	3.30	3.54	6.62	3.48
	North of Shetland	7.32	27.52	6.50	1.30	5.92
	Northern North Sea	0.00	0.73	2.55	0.00	0.00
	Outer Moray Firth	0.00	0.00	0.00	0.00	0.00
	Central North Sea	0.00	0.38	0.45	0.27	0.00
	Southern North Sea	0.00	0.00	0.00	0.00	0.00
White-beaked dolphin	West of Shetland	1.85	13.22	1.77	1.32	0.00
	North of Shetland	3.66	1.45	4.33	1.30	0.00
	Northern North Sea	7.70	9.81	7.65	4.90	4.38
	Outer Moray Firth	31.55	24.61	13.42	10.51	9.31
	Central North Sea	18.63	34.18	10.88	14.04	19.04
	Southern North Sea	4.86	3.66	2.86	8.67	0.00
Atlantic white-sided dolphin	West of Shetland	48.22	40.76	20.65	7.28	3.48
	North of Shetland	14.63	8.69	9.38	2.60	2.96
	Northern North Sea	9.62	4.36	0.43	0.61	0.00
	Outer Moray Firth	0.00	3.79	2.24	0.00	0.00
	Central North Sea	5.08	1.13	0.00	1.35	0.00
	Southern North Sea	0.00	0.00	0.00	0.00	0.00
Harbour porpoise	West of Shetland	9.27	0.00	1.77	1.32	1.16
	North of Shetland	1.22	11.59	1.44	0.00	0.00
	Northern North Sea	5.77	5.09	2.55	4.90	5.84
	Outer Moray Firth	0.00	5.68	15.65	21.02	27.94
	Central North Sea	1.69	6.38	2.72	3.78	11.72
	Southern North Sea	0.00	1.83	28.56	42.12	0.00

3.2 Effects of geophysical operations on marine mammals

3.2.1 Detection rates (active source versus not active)

On surveys with large arrays of airguns, detection rates were significantly higher when the airguns were not firing for the grey seal, minke whale, killer whale, white-beaked dolphin, Atlantic white-sided dolphin, common dolphin, and the harbour porpoise (Table 4). On surveys with small arrays of airguns, detection rates were significantly higher for minke whales, sperm whales and harbour porpoises when the airguns were not active, although sample sizes for many species were low (Table 4). Sample sizes were also low for high resolution surveys, although for the combined group of all cetacean detection rates were significantly higher when pingers were not active (Table 4).

Table 4. Marine mammal detection rates in relation to acoustic source activity, tested using the Wilcoxon signed ranks test (T+ = sum of ranks of pairs where detection rate when not active exceeded detection rate when active; z = Wilcoxon statistic for large samples; n = number of matched pairs of detection rates at different source activities; d.f. = 1). Significant results are in bold.

Airguns: large arrays

Species	Median detection rate per hour (+ 1st and 3rd quartiles)						T^+	z	n	p-value
	Not active			Active						
Grey seal	*0.00*	0.11	*0.51*	*0.00*	0.00	0.10	2,671.5	3.207	87	**< 0.001**
Harbour seal	*0.00*	0.00	*0.10*	*0.00*	0.07	0.19	36	-	13	0.729
Humpback whale	*0.00*	0.00	*0.10*	*0.00*	0.05	0.27	36	-	13	0.729
Fin whale	*0.00*	0.04	*0.14*	*0.00*	0.05	0.14	3,2445	0.069	113	0.472
Sei whale	*0.00*	0.00	*0.16*	*0.00*	0.07	0.24	94	-0.749	21	0.227
Minke whale	*0.00*	0.07	*0.24*	*0.00*	0.00	0.16	67,894	3.890	474	**< 0.001**
Sperm whale	*0.00*	0.08	*0.22*	*0.00*	0.04	0.19	6,537	0.879	155	0.189
All beaked whales	*0.01*	0.09	*0.26*	*0.00*	0.00	0.06	51	-	12	0.190
Long-finned pilot whale	*0.00*	0.00	*0.18*	*0.00*	0.05	0.19	10,616	-0.289	208	0.386
Killer whale	*0.03*	0.11	*0.23*	*0.00*	0.00	0.07	7,139	4.781	139	**< 0.001**
Risso's dolphin	*0.00*	0.08	*0.17*	*0.00*	0.00	0.16	461	0.107	40	0.456
Bottlenose dolphin	*0.00*	0.04	*0.17*	*0.00*	0.00	0.14	647	0.605	48	0.271
White-beaked dolphin	*0.03*	0.12	*0.28*	*0.00*	0.00	0.10	93,019	8.573	508	**< 0.001**
Atlantic white-sided dolphin	*0.00*	0.08	*0.20*	*0.00*	0.00	0.11	36,367	4.070	340	**< 0.001**

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Not active			Active			T+	z	n	p-value
Common dolphin	*0.00*	0.14	*0.36*	*0.00*	0.00	0.11	2,298.5	3.004	81	**0.001**
Harbour porpoise	*0.04*	0.18	*0.39*	*0.00*	0.00	0.08	16,440	7.265	203	**< 0.001**

Airguns: small arrays

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Not active			Active			T+	z	n	p-value
Grey seal	*0.00*	0.02	*0.29*	*0.00*	0.07	0.38	36	-	14	0.837
All mysticetes combined	*0.00*	0.08	*0.31*	*0.00*	0.06	0.18	1,274.5	0.620	68	0.268
Fin whale	*0.07*	0.07	*0.12*	*0.10*	0.14	0.17	5	-	5	0.688
Minke whale	*0.00*	0.10	*0.39*	*0.00*	0.00	0.12	875	1.694	52	**0.046**
Sperm whale	*0.08*	0.15	*0.27*	*0.00*	0.00	0.07	171	1.929	21	**0.027**
All delphinids combined	*0.00*	0.11	*0.36*	*0.00*	0.07	0.27	10,781	1.554	195	0.061
Long-finned pilot whale	*0.00*	0.11	*0.50*	*0.00*	0.00	0.28	112	0.684	19	0.248
Killer whale	*0.00*	0.01	*0.10*	*0.00*	0.02	0.21	13	-	8	0.727
Risso's dolphin	*0.00*	0.12	*0.21*	*0.00*	0.00	0.88	14	-	7	0.531
Bottlenose dolphin	*0.00*	0.00	*0.24*	*0.00*	0.03	0.08	14	-	7	0.531
White-beaked dolphin	*0.00*	0.12	*0.46*	*0.00*	0.00	0.24	389	1.213	35	0.113
Atlantic white-sided dolphin	*0.00*	0.10	*0.24*	*0.00*	0.00	0.14	679	1.217	47	0.111
Common dolphin	*0.00*	0.19	*0.60*	*0.00*	0.28	0.46	13	-	7	0.531
Harbour porpoise	*0.00*	0.16	*0.31*	*0.00*	0.00	0.12	167	1.790	21	**0.037**

Chirp

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Not active			Active			T+	z	n	p-value
All cetaceans combined	*0.00*	0.00	*0.73*	*0.00*	*1.33*	3.00	5	-	6	0.844

Pinger

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Not active			Active			T+	z	n	p-value
All seals combined	*0.00*	0.00	*0.47*	*0.00*	0.05	0.23	28	-	9	0.285
All cetaceans combined	*0.23*	0.74	*1.26*	*0.00*	0.00	0.30	63	-	12	**0.032**

3.2.2 Detection rates prior to and post operations commencing

For large arrays of airguns, detection rates in the week prior to operations commencing did not differ significantly from detection rates in the week after commencement, except for the harbour porpoise where detection rates were higher prior to operations commencing (Table 5). For small arrays of airguns, no significant differences were found for any of the species or species groups tested. Sample sizes were low for individual species.

Table 5. Marine mammal detection rates in the week prior to operations commencing compared to the week after operations commenced, tested using the Wilcoxon signed ranks test (T+ = sum of ranks of pairs where detection rate prior to operations commencing exceeded detection rate after operations commenced; z = Wilcoxon statistic for large samples; n = number of matched pairs of detection rates prior to and post operations commencing; d.f. = 1). Significant results are in bold.

Airguns: large arrays

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Prior to operations commencing			Post operations commencing			T+	z	n	p-value
All seals combined	*0.00*	**0.04**	*0.12*	*0.00*	**0.02**	0.05	16	-	8	0.578
All cetaceans combined	*0.00*	**0.06**	*0.30*	*0.00*	**0.09**	0.30	4,385.5	0.298	130	0.382
All mysticetes combined	*0.00*	**0.04**	*0.12*	*0.00*	**0.05**	0.20	129	-1.441	27	0.075
Fin whale	*0.00*	**0.04**	*0.08*	*0.00*	**0.00**	0.13	8	-	7	0.813
Minke whale	*0.00*	**0.00**	*0.09*	*0.00*	**0.06**	0.16	62	-1.023	18	0.154
Sperm whale	*0.00*	**0.12**	*0.43*	*0.00*	**0.00**	0.06	40	-	10	0.116
Long-finned pilot whale	*0.00*	**0.11**	*0.46*	*0.00*	**0.03**	0.23	37.5	-	10	0.174
Killer whale	*0.00*	**0.00**	*0.07*	*0.00*	**0.08**	0.14	19	-	9	0.633
All delphinids combined	*0.00*	**0.00**	*0.21*	*0.00*	**0.08**	0.23	2,229	-0.362	96	0.359

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Prior to operations commencing			Post operations commencing			T^+	z	n	p-value
Bottlenose dolphin	*0.00*	**0.00**	*0.00*	*0.08*	**0.09**	0.14	0	-	5	0.969
White-beaked dolphin	*0.00*	**0.02**	*0.17*	*0.00*	**0.04**	0.16	266	0.037	32	0.484
Atlantic white-sided dolphin	*0.00*	**0.00**	*0.06*	*0.00*	**0.06**	0.09	77.5	-1.326	21	0.092
Harbour porpoise	*0.09*	**0.24**	*0.40*	*0.00*	**0.00**	0.00	27	-	7	**0.016**

Airguns: small arrays

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Prior to operations commencing			Post operations commencing			T^+	z	n	p-value
All cetaceans combined	*0.00*	*0.00* **0.12** *0.44*	*0.44*	*0.08*	**0.15**	0.50	113	-0.761	23	0.224
All mysticetes combined	*0.00*	*0.00* **0.25** *0.44*	*0.44*	*0.00*	**0.07**	0.57	15	-	7	0.469
Minke whale	*0.17*	*0.17* **0.33** *0.44*	*0.44*	*0.00*	**0.04**	0.44	15	-	6	0.219
All delphinids combined	*0.00*	*0.00* **0.00** *0.41*	*0.41*	*0.10*	**0.15**	0.38	42	-	15	0.835
White-beaked dolphin	*0.00*	*0.00* **0.00** *0.00*	*0.00*	*0.10*	**0.13**	0.15	4	-	5	0.781
Harbour porpoise	*0.13*	*0.13* **0.37** *0.40*	*0.40*	*0.00*	**0.00**	0.00	8	-	5	0.500

3.2.3 Closest distance of approach to the source (active versus not active)

Marine mammals often approached closer to large arrays of airguns when they were inactive compared to when they were active (Figure 7; Table 6). This was statistically significant for the minke whale, killer whale, bottlenose dolphin, white-beaked dolphin, Atlantic white-sided dolphin, common dolphin, and the harbour porpoise. With small arrays of airguns, marine mammals were often closer when the airguns were active, but this was not statistically significant for any of the species or species groups where sample sizes were sufficient to test (Figure 8; Table 6). For high resolution sources sample sizes were low and could only be tested for chirps with all cetaceans combined; cetaceans approached closer to the chirp when it was not active (Figure 9; Table 6).

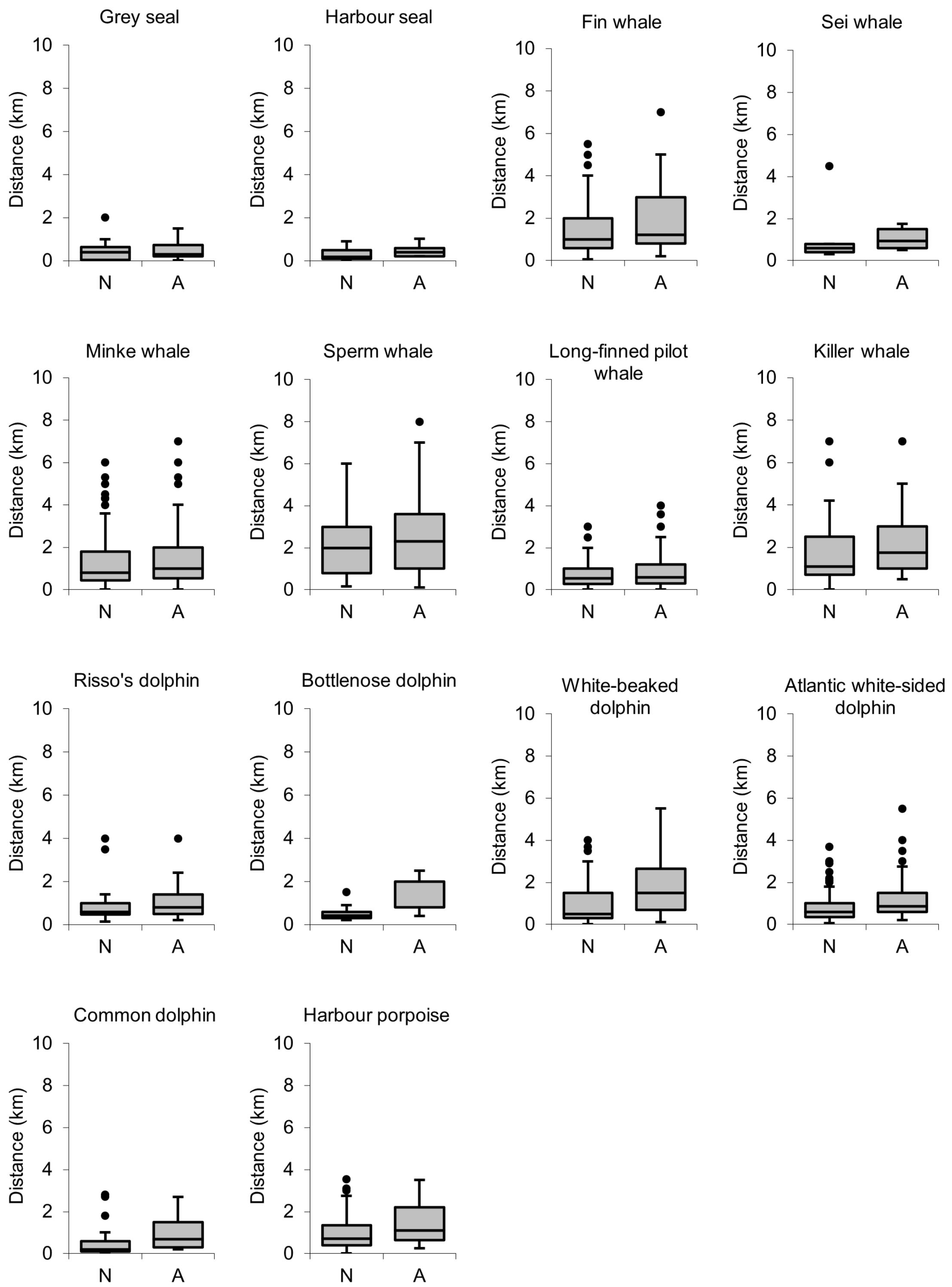


Figure 7. Box-and-whisker plots of closest distance of approach to large arrays of airguns relative to activity (N = not active; A = active). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers and dots show outliers (> 1.5 x interquartile range outside the 1st or 3rd quartile).

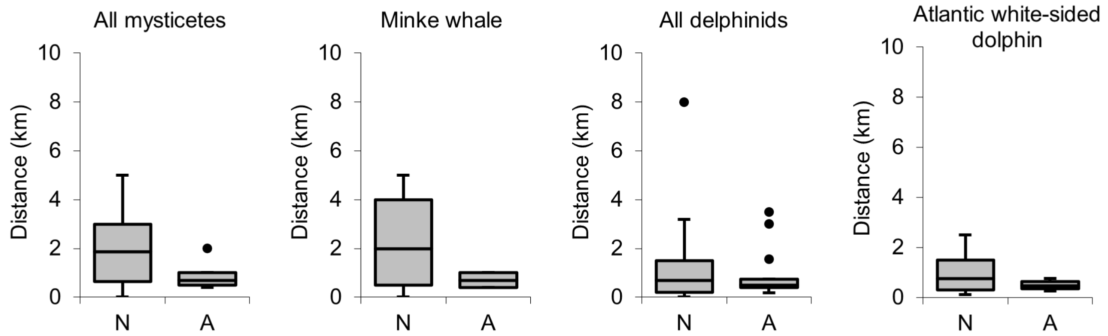


Figure 8. Box-and-whisker plots of closest distance of approach to small arrays of airguns relative to activity (N = not active; A = active). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers and dots show outliers (> 1.5 x interquartile range outside the 1st or 3rd quartile).

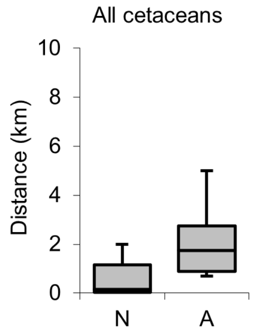


Figure 9. Box-and-whisker plot of closest distance of approach to chirps relative to activity (N = not active; A = active). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers and dots show outliers (> 1.5 x interquartile range outside the 1st or 3rd quartile).

Table 6. Closest distance of approach of marine mammals to the source in relation to source activity, tested using the Wilcoxon-Mann-Whitney test (Wx = sum of ranks of the smallest group; z = Wilcoxon statistic for large samples; n = sample size; d.f. = 1). Significant results are in bold.

Airguns: large arrays

Species	Median closest distance (metres)		W_x	z	n	p-value
	Not active	Active				
Grey seal	400	300	760.5	0.618	59	0.268
Harbour seal	190	400	26	-0.983	12	0.164
Fin whale	1,000	1,200	3,535	1.606	115	0.054
Sei whale	600	1,000	25.5	-0.915	11	0.179
Minke whale	800	1,000	33,021.5	2.087	369	**0.018**
Sperm whale	2,000	2,500	4,523	-1.424	140	0.078
Long-finned pilot whale	537.5	600	3,792.5	-0.773	131	0.221
Killer whale	1,200	1,875	1,678.5	2.114	91	**0.017**
Risso's dolphin	600	800	197	-0.547	29	0.291
Bottlenose dolphin	425	2,000	116	2.880	21	**0.002**

Species	Median closest distance (metres)		W_x	z	n	p-value
	Not active	Active				
White-beaked dolphin	500	1,500	32,912.5	6.740	381	**< 0.001**
Atlantic white-sided dolphin	600	835	9,841	3.524	230	**< 0.001**
Common dolphin	211.5	700	514	2.898	43	**0.002**
Harbour porpoise	725	1,100	6,133.5	3.280	195	**< 0.001**

Airguns: small arrays

Species	Median closest distance (metres)		W_x	z	n	p-value
	Not active	Active				
All mysticetes combined	1,875	1,000	82	-1.509	32	0.066
Minke whale	2,000	700	24	-0.962	22	0.169
All delphinids combined	700	500	614	-0.080	72	0.468
Atlantic white-sided dolphin	750	475	77	-0.763	21	0.224

Chirp

Species	Median closest distance (metres)		W_x	z	n	p-value
	Not active	Active				
All cetaceans combined	165	2,000	14.5	-	12	**0.030**

3.2.4 Behaviour (active source versus not active)

Airgun activity sometimes affected the movement of marine mammals around the vessel. Long-finned pilot whales, killer whales, white-beaked dolphins, Atlantic white-sided dolphins, common dolphins and the combined groups of all seals and all mysticetes engaged in interactions with the vessel or its equipment (e.g. bow-riding) or travelled towards the vessel significantly less when large arrays were firing (Table 7). Similarly, minke whales, long-finned pilot whales, white-beaked dolphins, Atlantic white-sided dolphins, harbour porpoises and the combined group of all seals were described as avoiding the vessel or travelled away from it more often when large arrays were firing. Minke whales, long-finned pilot whales and white-beaked dolphins also altered course more often at these times; in the case of white-beaked dolphins 62% of these course alterations were away from the vessel.

Swimming behaviour was also affected. Minke whales, bottlenose dolphins, white-beaked dolphins, and seals (all species combined) were more likely to be described as swimming fast when large arrays were active (Table 7). However, not all responses were the same, as long-finned pilot whales were recorded more often as swimming slowly at these times. Killer whales and the combined group of all delphinids were more likely to be breaching or jumping and white-beaked dolphins and the combined group of all mysticetes more likely to be splashing when large arrays were active. Groups of cetaceans (all species combined) were described as dispersed more often when the airguns were not active.

There were some indications that marine mammals may have been staying close to the surface when large arrays of airguns were active. Although results for individual species were not significant, when all cetaceans or all mysticetes were combined they were significantly more likely to be described as surfacing often when airguns were active and surfacing infrequently when airguns were not active (Table 7). Delphinids were also recorded as surfacing infrequently more often when airguns were inactive while spy-hopping in this group was more likely when airguns were active. Cetaceans (all species combined) were more likely to be recorded as logging or resting at the surface when the airguns were active. However, long-finned pilot whales again responded differently, with more diving when large arrays were active.

Feeding was sometimes observed less often when large arrays of airguns were active; the difference in numbers feeding was not significant for individual species but was significant when all cetaceans were combined (Table 7).

Fewer behavioural responses were observed when small arrays of airguns were active (Table 8). The only significant result for an individual species was for Atlantic white-sided dolphins, which only engaged in interactions with the vessel or its equipment or travelled towards the vessel when the airguns were not active. The combined group of all delphinids also interacted with or travelled towards the vessel more often when the airguns were inactive. Breaching or jumping and splashing were more prevalent amongst cetaceans (all species combined) seen when small arrays were active. There were no clear trends in surfacing behaviour with small arrays of airguns; both surfacing frequently and surfacing infrequently were more prevalent amongst cetaceans seen when the airguns were active.

Table 7. Behaviour of marine mammals in relation to source activity on surveys with large arrays of airguns, tested using the chi-squared test (n = number of sightings where the behaviour was exhibited; d.f. = 1). Significant results are in bold.

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited: Not active		Active		χ^2	n	p-value
Altered course	Fin whale	8	(4.1%)	11	(7.0%)	1.35	19	< 0.30
	Minke whale	10	(1.7%)	15	(3.9%)	4.46	25	**< 0.05**
	Long-finned pilot whale	15	(4.9%)	34	(10.3%)	6.13	49	**< 0.02**
	White-beaked dolphin	5	(0.6%)	13	(3.8%)	17.46	18	**< 0.001**
	Atlantic white-sided dolphin	12	(2.7%)	10	(4.6%)	1.64	22	< 0.20
Avoidance or travel away from vessel / equipment	All seals combined	30	(11.7%)	42	(22.8%)	8.07	72	**< 0.01**
	Grey seal	17	(12.9%)	10	(14.5%)	0.09	27	< 0.80
	Fin whale	29	(14.8%)	36	(22.8%)	3.04	65	< 0.10
	Minke whale	50	(8.4%)	60	(15.5%)	10.61	110	**< 0.01**
	Sperm whale	39	(16.2%)	39	(20.3%)	1.01	78	< 0.50
	Long-finned pilot whale	16	(5.2%)	40	(12.1%)	8.70	56	**< 0.01**
	Killer whale	34	(12.4%)	16	(14.7%)	0.31	50	< 0.70
	White-beaked dolphin	75	(8.4%)	65	(18.7%)	23.63	140	**< 0.001**
	Atlantic white-sided dolphin	28	(6.3%)	24	(11.1%)	4.32	52	**< 0.05**
	Harbour porpoise	74	(20.1%)	46	(37.1%)	11.08	120	**< 0.001**
Bottling	Grey seal	29	(22.0%)	14	(20.3%)	0.06	43	< 0.90
Breaching / jumping	Minke whale	38	(6.4%)	33	(8.5%)	1.51	71	< 0.30
	All delphinids combined	1,064	(30.6%)	640	(34.5%)	5.68	1,704	**< 0.02**
	Long-finned pilot whale	16	(5.2%)	27	(8.2%)	2.11	43	< 0.20
	Killer whale	23	(8.4%)	18	(16.5%)	4.80	41	**< 0.05**
	Risso’s dolphin	7	(15.9%)	11	(36.7%)	3.16	18	< 0.10
	Bottlenose dolphin	18	(29.0%)	19	(54.3%)	3.74	37	< 0.10
	White-beaked dolphin	303	(33.9%)	143	(41.2%)	3.68	446	< 0.10
	Atlantic white-sided dolphin	198	(44.4%)	102	(47.2%)	0.26	300	< 0.70
	Common dolphin	57	(32.0%)	26	(36.1%)	0.26	83	< 0.70
Close group	Long-finned pilot whale	10	(3.3%)	5	(1.5%)	2.03	15	< 0.70
	White-beaked dolphin	22	(2.5%)	7	(2.0%)	0.22	29	< 0.70
	Atlantic white-sided dolphin	15	(3.4%)	7	(3.2%)	0.01	22	< 0.95

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited				χ^2	n	p-value
		Not active		Active				
Dispersed group	All cetaceans combined	149	(2.5%)	66	(1.8%)	4.57	215	**< 0.05**
	Long-finned pilot whale	7	(2.3%)	14	(4.2%)	1.88	21	< 0.20
	Killer whale	14	(5.1%)	4	(3.7%)	0.34	18	< 0.80
	White-beaked dolphin	25	(2.8%)	10	(2.9%)	0.01	35	< 0.95
	Atlantic white-sided dolphin	49	(11.0%)	13	(6.0%)	3.83	62	< 0.10
Diving	Grey seal	35	(26.5%)	21	(30.4%)	0.25	56	< 0.70
	Fin whale	20	(10.2%)	24	(15.2%)	1.75	44	< 0.20
	Minke whale	73	(12.3%)	51	(13.2%)	0.16	124	< 0.70
	Sperm whale	120	(49.8%)	83	(43.2%)	0.98	203	< 0.50
	Long-finned pilot whale	15	(4.9%)	34	(10.3%)	6.13	49	**< 0.02**
	Killer whale	13	(4.7%)	8	(7.3%)	0.95	21	< 0.50
	White-beaked dolphin	15	(1.7%)	6	(1.7%)	0.00	21	< 0.98
Fast swimming	All seals combined	6	(2.3%)	12	(6.5%)	4.56	18	**< 0.05**
	Fin whale	14	(7.1%)	20	(12.7%)	2.77	34	< 0.10
	Minke whale	64	(10.7%)	85	(22.0%)	19.51	149	**< 0.001**
	Long-finned pilot whale	45	(14.6%)	59	(17.9%)	1.05	104	< 0.50
	Killer whale	35	(12.8%)	20	(18.4%)	1.69	55	< 0.20
	Risso's dolphin	10	(22.7%)	5	(16.7%)	0.32	15	< 0.70
	Bottlenose dolphin	14	(22.6%)	17	(48.6%)	4.72	31	**< 0.05**
	White-beaked dolphin	232	(26.0%)	123	(35.5%)	7.83	355	**< 0.01**
	Atlantic white-sided dolphin	209	(46.9%)	116	(53.7%)	1.39	325	< 0.30
	Common dolphin	60	(33.7%)	29	(40.3%)	0.62	89	< 0.50
	Harbour porpoise	70	(19.0%)	26	(21.0%)	0.19	96	< 0.70
Feeding	Grey seal	9	(6.8%)	6	(8.7%)	0.21	15	< 0.70
	All cetaceans combined	646	(10.6%)	343	(9.3%)	4.00	989	**< 0.05**
	Fin whale	26	(13.3%)	17	(10.8%)	0.45	43	< 0.70
	Minke whale	18	(3.0%)	12	(3.1%)	0.01	30	< 0.95
	Long-finned pilot whale	24	(7.8%)	28	(8.5%)	0.09	52	< 0.80
	Killer whale	80	(29.2%)	23	(21.1%)	1.90	103	< 0.20
	Bottlenose dolphin	9	(14.5%)	6	(17.1%)	0.10	15	< 0.80
	White-beaked dolphin	100	(11.2%)	52	(15.0%)	2.92	152	< 0.10

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited				χ^2	n	p-value
		Not active		Active				
	Atlantic white-sided dolphin	102	(22.9%)	45	(20.8%)	0.27	147	< 0.70
	Common dolphin	18	(10.1%)	5	(6.9%)	0.82	23	< 0.50
	Harbour porpoise	20	(5.4%)	11	(8.9%)	1.75	31	< 0.20
In subgroups	Long-finned pilot whale	7	(2.3%)	7	(2.1%)	0.02	14	< 0.95
	Atlantic white-sided dolphin	13	(2.9%)	3	(1.4%)	1.40	16	< 0.30
Logging / resting	Grey seal	14	(10.6%)	12	(17.4%)	1.61	26	< 0.30
	All cetaceans combined	140	(2.3%)	113	(3.1%)	5.13	253	**< 0.05**
	Sperm whale	73	(30.3%)	65	(33.9%)	0.43	138	< 0.70
	Long-finned pilot whale	28	(9.1%)	24	(7.3%)	0.65	52	< 0.50
Milling	All mysticetes combined	12	(1.1%)	19	(2.2%)	3.81	31	< 0.10
	Long-finned pilot whale	18	(5.8%)	16	(4.9%)	0.30	34	< 0.70
	Killer whale	17	(6.2%)	6	(5.5%)	0.07	23	< 0.80
	White-beaked dolphin	28	(3.1%)	11	(3.2%)	0.00	39	< 0.98
	Atlantic white-sided dolphin	13	(2.9%)	9	(4.2%)	0.69	22	< 0.50
Porpoising	Long-finned pilot whale	19	(6.2%)	22	(6.7%)	0.72	41	< 0.90
	Bottlenose dolphin	7	(11.3%)	8	(22.9%)	1.94	15	< 0.20
	White-beaked dolphin	128	(14.3%)	58	(16.7%)	0.94	186	< 0.50
	Atlantic white-sided dolphin	144	(32.2%)	61	(28.2%)	0.77	205	< 0.50
	Common dolphin	36	(20.2%)	16	(22.2%)	0.10	52	< 0.80
	Harbour porpoise	23	(6.2%)	5	(4.0%)	0.79	28	< 0.50
Interactions with or travel towards vessel / equipment	All seals combined	20	(7.8%)	8	(4.4%)	8.89	28	**< 0.01**
	Grey seal	11	(8.3%)	6	(8.7%)	0.01	17	< 0.95
	All mysticetes combined	69	(6.3%)	29	(3.4%)	8.16	98	**< 0.01**
	Fin whale	16	(8.2%)	7	(4.4%)	1.88	23	< 0.20
	Minke whale	41	(6.9%)	16	(4.1%)	3.05	57	< 0.10
	Sperm whale	12	(5.0%)	10	(5.2%)	0.01	22	< 0.95
	Long-finned pilot whale	77	(25.0%)	53	(16.1%)	6.25	130	**< 0.02**
	Killer whale	25	(9.1%)	1	(0.9%)	7.34	26	**< 0.01**
	Bottlenose dolphin	12	(19.4%)	4	(11.4%)	0.85	16	< 0.50
	White-beaked dolphin	321	(36.0%)	55	(15.6%)	33.28	376	**< 0.001**
	Atlantic white-sided dolphin	60	(13.5%)	16	(7.4%)	4.64	76	**< 0.05**
	Common dolphin	95	(53.4%)	18	(25.0%)	9.13	113	**< 0.01**

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited				χ^2	n	p-value
		Not active		Active				
Slow swimming	Grey seal	20	(15.2%)	11	(15.9%)	0.02	31	< 0.90
	Fin whale	36	(18.4%)	28	(17.7%)	0.02	64	< 0.90
	Minke whale	142	(23.8%)	89	(23.0%)	0.07	231	< 0.80
	Sperm whale	45	(18.7%)	36	(18.8%)	0.00	81	1.00
	Long-finned pilot whale	90	(29.2%)	137	(41.5%)	6.77	227	**< 0.01**
	Killer whale	61	(22.3%)	21	(19.3%)	0.33	82	< 0.70
	Risso's dolphin	17	(38.6%)	14	(46.7%)	0.27	31	< 0.70
	Bottlenose dolphin	15	(24.2%)	5	(14.3%)	1.07	20	< 0.50
	White-beaked dolphin	88	(9.9%)	22	(6.3%)	3.48	110	< 0.10
	Atlantic white-sided dolphin	54	(12.1%)	16	(7.4%)	3.04	70	< 0.10
	Harbour porpoise	99	(26.8%)	38	(30.7%)	0.49	137	< 0.50
Splashing	All mysticetes combined	257	(0.4%)	186	(1.2%)	4.30	14	**< 0.05**
	Killer whale	12	(4.4%)	7	(6.4%)	0.65	19	< 0.50
	White-beaked dolphin	43	(4.8%)	28	(8.1%)	4.62	71	**< 0.05**
	Atlantic white-sided dolphin	12	(2.7%)	11	(5.1%)	2.42	23	< 0.20
Spy-hopping / looking around	Grey seal	15	(11.4%)	10	(14.5%)	0.36	25	< 0.70
	All delphinids combined	31	(0.9%)	29	(1.6%)	4.84	60	**< 0.05**
	Long-finned pilot whale	20	(6.5%)	24	(7.3%)	0.14	44	< 0.80
Surfacing frequently	All cetaceans combined	53	(0.9%)	52	(1.4%)	6.18	105	**< 0.02**
	All mysticetes combined	16	(1.5%)	26	(3.0%)	5.26	42	**< 0.02**
	Minke whale	8	(1.3%)	12	(3.1%)	3.57	20	< 0.10
	All delphinids combined	21	(0.6%)	16	(0.9%)	1.16	37	< 0.30
Surfacing infrequently	All cetaceans combined	346	(5.7%)	169	(4.6%)	5.37	515	**< 0.05**
	All mysticetes combined	132	(12.1%)	60	(7.0%)	12.49	192	**< 0.001**
	Fin whale	15	(7.7%)	10	(6.3%)	0.22	25	< 0.70
	Minke whale	84	(14.1%)	39	(10.0%)	3.02	123	< 0.10
	Sperm whale	6	(2.5%)	7	(3.7%)	0.48	13	< 0.50
	All delphinids combined	99	(2.9%)	31	(1.7%)	6.88	130	**< 0.01**
	Harbour porpoise	18	(4.9%)	11	(8.9%)	2.52	29	< 0.20
Swimming at or just below surface	All cetaceans combined	19	(0.3%)	16	(0.4%)	0.94	35	< 0.50
	All delphinids combined	11	(0.3%)	4	(0.2%)	0.44	15	< 0.70

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited: Not active		Active		χ^2	n	p-value
Tail-slapping	Long-finned pilot whale	7	(2.3%)	16	(4.9%)	2.93	23	< 0.10
	Killer whale	11	(4.0%)	7	(6.4%)	0.97	18	< 0.50

Table 8. Behaviour of marine mammals in relation to source activity on surveys with small arrays of airguns, tested using the chi-squared test (n = number of sightings where the behaviour was exhibited; d.f. = 1). Significant results are in bold.

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited: Not active		Active		χ^2	n	p-value
Avoidance or travel away from vessel / equipment	All cetaceans combined	106	(10.6%)	46	(13.7%)	2.18	152	< 0.20
	All mysticetes combined	14	(8.3%)	7	(12.3%)	0.71	21	< 0.50
	All delphinids combined	45	(8.4%)	22	(11.9%)	1.83	67	< 0.20
Breaching / jumping	All cetaceans combined	180	(17.9%)	86	(25.6%)	7.45	266	**< 0.01**
	Minke whale	13	(10.5%)	8	(20.0%)	2.14	21	< 0.20
	White-beaked dolphin	37	(27.2%)	14	(40.0%)	1.53	51	< 0.30
	Atlantic white-sided dolphin	30	(38.0%)	16	(44.4%)	0.26	46	< 0.70
Dispersed group	Atlantic white-sided dolphin	12	(15.2%)	6	(16.7%)	0.04	18	< 0.90
Diving	All seals combined	14	(19.7%)	4	(13.3%)	0.49	18	< 0.50
	All cetaceans combined	76	(7.6%)	18	(5.4%)	1.76	94	< 0.20
	Minke whale	18	(14.5%)	3	(7.5%)	1.16	21	< 0.30
Fast swimming	White-beaked dolphin	33	(24.3%)	7	(20.0%)	0.22	40	< 0.70
	Atlantic white-sided dolphin	30	(38.0%)	12	(33.3%)	0.15	42	< 0.80
Feeding	All cetaceans combined	100	(10.0%)	33	(9.8%)	0.01	133	< 0.95
	All delphinids combined	69	(12.9%)	27	(14.6%)	0.32	96	< 0.70
	Atlantic white-sided dolphin	11	(13.9%)	9	(25.0%)	1.75	20	< 0.20
Milling	All cetaceans combined	48	(4.8%)	12	(3.6%)	0.82	60	< 0.50
	All delphinids combined	32	(6.0%)	10	(5.4%)	0.07	42	< 0.80
Porpoising	All delphinids combined	58	(10.8%)	24	(13.0%)	0.57	82	< 0.50
	Atlantic white-sided dolphin	19	(24.1%)	6	(16.7%)	0.62	25	< 0.50
Interactions with or travel towards vessel / equipment	All delphinids combined	189	(35.2%)	26	(14.1%)	20.65	215	**<0.001**
	White-beaked dolphin	87	(64.0%)	17	(48.6%)	1.09	104	< 0.30
	Atlantic white-sided dolphin	18	(22.8%)	0	(0.0%)	8.19	18	**< 0.01**
	Common dolphin	21	(65.6%)	4	(50.0%)	0.25	25	< 0.70

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited				χ^2	n	p-value
		Not active		Active				
Slow swimming	All cetaceans combined	150	(14.9%)	35	(10.4%)	3.73	185	< 0.10
	Minke whale	26	(21.0%)	6	(15.0%)	0.55	32	< 0.50
	All delphinids combined	73	(13.6%)	20	(10.8%)	0.83	93	< 0.50
	Atlantic white-sided dolphin	13	(16.5%)	7	(19.4%)	0.13	20	< 0.80
Splashing	All cetaceans combined	10	(1.0%)	11	(3.3%)	8.32	21	**< 0.01**
Surfacing frequently	All cetaceans combined	10	(1.0%)	10	(3.0%)	6.63	20	**< 0.02**
Surfacing infrequently	All cetaceans combined	37	(3.7%)	24	(7.1%)	6.60	61	**< 0.02**
	All delphinids combined	16	(3.0%)	9	(4.9%)	1.41	25	< 0.30

3.2.5 Effectiveness of the soft start

For all species or species groups that were able to be tested there were significant differences in detection rates with source activity, with both large arrays and small arrays of airguns (Table 9). These included some cases (sperm whale, long-finned pilot whale and bottlenose dolphin for large arrays; all delphinids combined for small arrays) where the longer term analysis comparing detection rates when the source was active (including any state of activity) to those when the source was inactive had not found a significant difference (section 3.2.1); however in all these cases, multiple comparisons found no difference between detection rates when the source was not active and detection rates at full power (which would have accounted for the majority of the time when the source was active during the longer term analysis, as soft starts are of a relatively short duration).

In all cases multiple comparisons showed that detection rates during the soft start were significantly lower than detection rates when the source was not active (Table 9). In some cases (minke whale, sperm whale, long-finned pilot whale, bottlenose dolphin, white-beaked dolphin, and Atlantic white-sided dolphin for large arrays; all delphinids combined for small arrays), detection rates during the soft start were also lower than detection rates at full power.

As there were relatively few sightings during the soft start, the closest distance of approach could only be compared for a few species or species groups for surveys using large arrays of airguns (Figure 10). Significant differences in the closest distance of approach in relation to source activity were found for minke whale, white-beaked dolphin and harbour porpoise, and the combined groups of all mysticetes and all delphinids (Table 10). In all cases animals approached significantly closer to the source when it was not active compared to when it was at full power. There were only two cases where the closest distance of approach during the soft start differed significantly from that at other times: the combined group of all mysticetes approached closer during the soft start than at full power, while harbour porpoises were found to be significantly further from the source during the soft start compared to when the source was not active (Table 10).

Table 9. Marine mammal detection rates in relation to source activity (not active or soft start or full power) for the period July 2009 to December 2020, tested using the Friedman two-way analysis of variance by ranks (N = not active; S = soft start; F = full power; Fr = Friedman statistic; n = number of three-way matched samples for detection rates at the different source activities; d.f. = 2). Multiple pairwise comparisons of treatments were made using the Wilcoxon signed ranks test (T+ = sum of ranks of matched pairs where detection rate at the first activity exceeded detection rate at the second activity; z = Wilcoxon statistic for large samples; n = number of matched pairs; adjusted p-value = adjusted using the Bonferroni correction for multiple comparisons; d.f. =1). Significant results are in bold.

Airguns: large arrays

Species	Source activity	Median detection rate per hr *(+ 1st and 3rd quartiles)*	F_r	n	p-value	Pairwise comparisons				
						Pair	T^+	z	n	Adjusted p-value
Grey seal	N	*0.00* 0.03 *0.06*				N-F	544	2.149	39	**0.047**
	S	*0.00* 0.00 *0.00*	23.925	1,190	**< 0.001**	N-S	380	3.034	30	**0.004**
	F	*0.00* 0.01 *0.03*				F-S	232	1.870	25	0.092
Minke whale	N	*0.00* 0.03 *0.08*				N-F	6,1810.5	3.309	136	**0.002**
	S	*0.00* 0.00 *0.00*	73.500	1,190	**< 0.001**	N-S	3,911	6.330	94	**< 0.001**
	F	*0.00* 0.01 *0.03*				F-S	2,372	5.001	75	**< 0.001**
Sperm whale	N	*0.00* 0.03 *0.06*				N-F	373	0.036	38	1.000
	S	*0.00* 0.00 *0.00*	15.388	1,190	**< 0.001**	N-S	226	3.230	22	**0.002**
	F	*0.00* 0.02 *0.05*				F-S	242	3.163	23	**0.002**
Long-finned pilot whale	N	*0.00* 0.03 *0.08*				N-F	512	0.471	43	0.958
	S	*0.00* 0.00 *0.00*	18.052	1,190	**< 0.001**	N-S	382	2.206	32	**0.041**
	F	*0.00* 0.02 *0.06*				F-S	425	2.582	33	**0.015**
Killer whale	N	*0.00* 0.03 *0.05*				N-F	220	2.000	24	0.068
	S	*0.00* 0.00 *0.00*	14.475	1,190	**< 0.001**	N-S	154	2.374	19	**0.027**
	F	*0.00* 0.00 *0.03*				F-S	56	-	12	0.305
Bottlenose dolphin	N	*0.00* 0.01 *0.03*				N-F	111	0.224	20	1.000
	S	*0.00* 0.00 *0.00*	10.000	1,190	**< 0.01**	N-S	55	2.803	10	**0.008**
	F	*0.00* 0.01 *0.03*				F-S	55	-	10	**0.003**
White-beaked dolphin	N	*0.01* 0.04 *0.08*				N-F	2,901	4.178	87	**< 0.001**
	S	*0.00* 0.00 *0.00*	66.364	1,190	**< 0.001**	N-S	2,184	6.178	68	**< 0.001**
	F	*0.00* 0.00 *0.03*				F-S	583	3.492	37	**< 0.001**
Atlantic white-sided dolphin	N	*0.01* 0.04 *0.10*				N-F	430	2.265	34	**0.035**
	S	*0.00* 0.00 *0.00*	22.741	1,190	**< 0.001**	N-S	327	3.848	26	**< 0.001**
	F	*0.00* 0.00 *0.04*				F-S	91	-	14	**0.020**

Species	Source activity	Median detection rate per hr *(+ 1st and 3rd quartiles)*			F_r	n	p-value	Pairwise comparisons				
								Pair	T^+	z	n	Adjusted p-value
Harbour porpoise	N	*0.00*	0.22	*0.43*	46.712	1,190	**< 0.001**	N-F	1,672	5.218	61	**< 0.001**
	S	*0.00*	0.00	*0.00*				N-S	1,188	4.183	53	**< 0.001**
	F	*0.00*	0.00	*0.16*				F-S	222	0.793	27	0.644

Airguns: small arrays

Species	Source activity	Median detection rate per hr *(+ 1st and 3rd quartiles)*			F_r	n	p-value	Pairwise comparisons				
								Pair	T^+	z	n	Adjusted p-value
All cetaceans combined	N	*0.00*	0.14	*0.29*	33.651	686	**< 0.001**	N-F	2,320	3.106	81	**0.003**
	S	*0.00*	0.00	*0.00*				N-S	1,639	4.006	64	**< 0.001**
	F	*0.00*	0.00	*0.14*				F-S	603	1.570	43	0.175
All delphinids combined	N	*0.00*	0.09	*0.22*	21.821	686	**< 0.001**	N-F	963	1.898	54	0.086
	S	*0.00*	0.00	*0.00*				N-S	634	3.405	39	**< 0.001**
	F	*0.00*	0.00	*0.14*				F-S	327	2.368	29	**0.027**

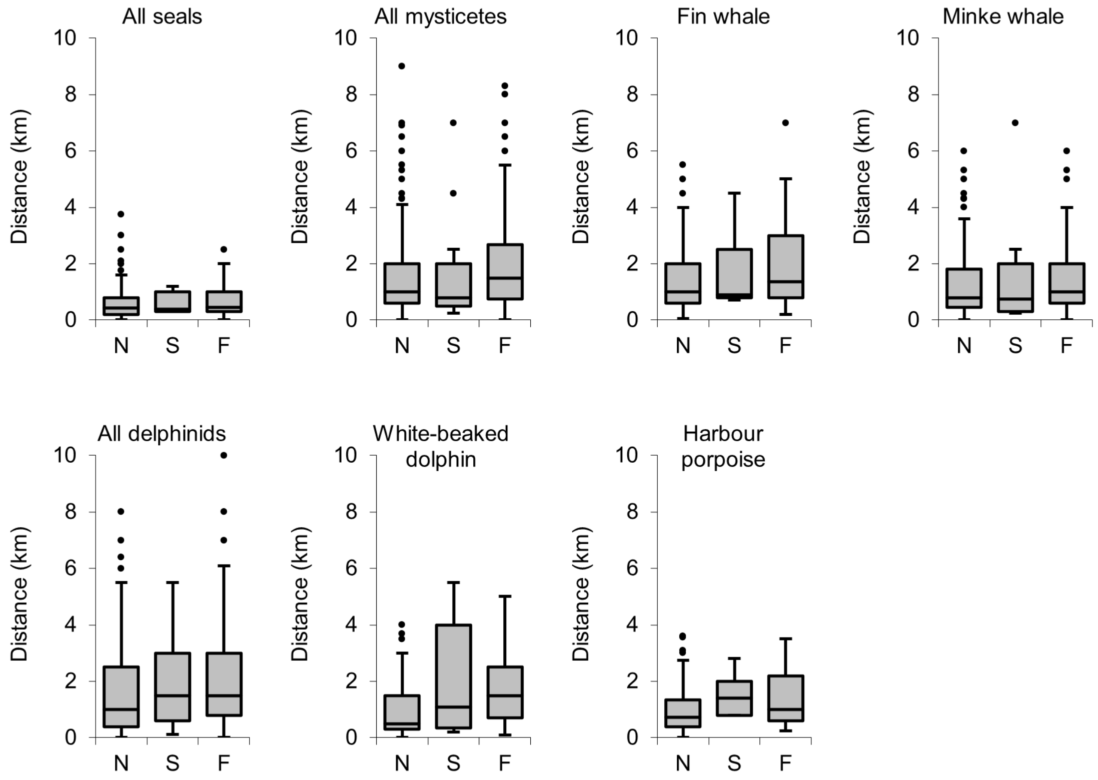


Figure 10. Box-and-whisker plots of closest distance of approach to large arrays of airguns relative to activity (N = not active; S = soft start; F = full power). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers and dots show outliers (greater than 1.5 x interquartile range outside the 1st or 3rd quartile).

Table 10. Closest distance of approach of marine mammals to the source in relation to source activity (not active or soft start or full power) on surveys with large arrays of airguns, tested using the Kruskall-Wallis one-way analysis of variance (N = not active; S = soft start; F = full power; KW = Kruskall-Wallis statistic; n = sample size; d.f. = 2). Multiple pairwise comparisons of treatments were made using Dunn's test (z = Dunn's test statistic; adjusted p-value = adjusted using the Bonferroni correction for multiple comparisons; d.f. = 1). Significant results are in bold.

Species	Source activity	Median closest distance of approach (metres)	KW	n	p-value	Pair	z	Adjusted p-value
All seals combined	N	425				-	-	-
	S	400	0.993	148	<0.700	-	-	-
	F	450				-	-	-
All mysticetes combined	N	1,000				N-F	3.913	**<0.001**
	S	800	17.408	676	**<0.001**	N-S	0.772	0.662
	F	1,500				F-S	2.158	**0.046**
Fin whale	N	1,000				-	-	-
	S	900	3.128	114	<0.300	-	-	-
	F	1,375				-	-	-
Minke whale	N	800				N-F	2.304	**0.032**
	S	750	6.060	366	**<0.050**	N-S	0.447	0.979
	F	1,000				F-S	1.388	0.247
All delphinids combined	N	1,000				N-F	6.453	**<0.001**
	S	1,500	42.200	1,556	**<0.001**	N-S	1.550	0.182
	F	1,500				F-S	0.586	0.833
White-beaked dolphin	N	500				N-F	6.642	**<0.001**
	S	1,100	44.977	380	**<0.001**	N-S	1.615	0.158
	F	1,500				F-S	0.401	1.000

Species	Source activity	Median closest distance of approach (metres)	KW	n	p-value	Pair	z	Adjusted p-value
Harbour porpoise	N	725				N-F	2.756	**0.009**
	S	1,400	11.491	193	**<0.010**	N-S	2.245	**0.037**
	F	1,000				F-S	0.944	0.521

When the first, closest and last distance to the source during the soft start period was recorded, significant differences were found (Table 11; Figure 11). For large arrays of airguns, both mysticetes and delphinids were found to be significantly closer to the airguns at some point during the soft start compared to their initial distance during the soft start. They were also found to be significantly further from the airguns when last detected during the soft start when compared to both their closest point of approach and the initial distance.

Table 11. Marine mammal distances from an airgun large array source throughout the soft start for the period July 2009 to December 2020, tested using the Friedman two-way analysis of variance by ranks (Fr = Friedman statistic; n = number of three-way matched samples for distances of an encounter throughout the soft start; d.f. = 2). Multiple pairwise comparisons of treatments were made using the Wilcoxon signed ranks test (F = first distance; C = closest distance; L = last distance; T+ = sum of ranks of matched pairs where distance for first treatment exceeded distance for second treatment; z = Wilcoxon statistic for large samples; n = number of matched pairs; adjusted p-value = adjusted using the Bonferroni correction for multiple comparisons; d.f. = 1). Significant results are in bold.

Species	Time of distance measurement during the soft start	Median distance (metres)	F_r	n	p-value	Pairwise comparisons				
						Pair	T^+	z	n	Adjusted p-value
All mysticetes combined	First	1,950				F-C	45	-	9	**0.006**
	Closest	1,500	29.861	28	**< 0.001**	L-C	231	4.113	21	**< 0.001**
	Last	2,000				L-F	162	2.254	20	**0.037**
All delphinids combined	First	1,250				F-C	174	3.767	18	**< 0.001**
	Closest	1,000	35.381	64	**< 0.001**	L-C	435	4.798	29	**< 0.001**
	Last	1,500				L-F	370	2.449	31	**0.021**

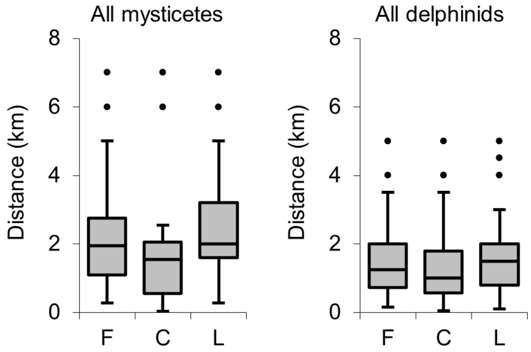


Figure 11. Box-and-whisker plots of distance from the source throughout the soft start for large arrays of airguns (F = first distance; C = closest distance; L = last distance). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers and dots show outliers (greater than 1.5 x interquartile range outside the 1st or 3rd quartile).

Although there were relatively few sightings during the soft start compared to when the source was not active or was at full power, some differences in behaviour were observed on surveys with large arrays of airguns (Table 12). Avoidance or travel away from the vessel was recorded in a greater proportion of sightings when the airguns were active, being slightly more prevalent during the soft start than at full power. This was the case for the combined groups of all mysticetes, all delphinids and all cetaceans, although it should be noted that many sightings did not display any avoidance. Travel away from the vessel was observed significantly more often during the soft start than at other times at distances of up to 2 km away from the source for delphinids and up to 3 km away for the combined group of all cetaceans (Table 13).

Table 12. Behaviour of marine mammals in relation to source activity (not active or soft start or full power), tested using the chi-squared test (n = number of sightings where the behaviour was exhibited; d.f. = 2). Significant results are in bold.

Airguns: large arrays

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited			χ^2	n	p-value
		Not active	Soft start	Full power			
Altered course	All cetaceans combined	93 (1.5%)	6 (2.6%)	126 (3.8%)	46.76	225	**< 0.001**
Avoidance or travel away from vessel / equipment	All cetaceans combined	711 (11.7%)	51 (21.7%)	640 (19.2%)	91.91	1,402	**< 0.001**
	All mysticetes combined	119 (10.9%)	9 (20.9%)	152 (19.3%)	23.66	280	**< 0.001**
	All delphinids combined	343 (9.9%)	26 (20.2%)	286 (17.2%)	119.76	655	**< 0.001**
Breaching / jumping	All delphinids combined	1,064(30.6%)	39 (30.2%)	575 (34.6%)	5.83	1,678	< 0.10
	White-beaked dolphin	303 (33.9%)	9 (27.3%)	127 (41.8%)	4.59	439	< 0.20
	Atlantic white-sided dolphin	198 (44.4%)	7 (43.8%)	91 (47.9%)	0.36	296	< 0.90
Dispersed group	All cetaceans combined	149 (2.5%)	6 (2.6%)	60 (1.8%)	4.22	215	< 0.20
Diving	All cetaceans combined	402 (6.6%)	20 (8.5%)	296 (8.9%)	15.21	718	**< 0.001**
	All mysticetes combined	125 (11.5%)	5 (11.6%)	109 (13.9%)	2.13	239	< 0.50
	Sperm whale	120 (49.8%)	5 (45.5%)	76 (43.4%)	0.62	201	< 0.80
Fast swimming	All mysticetes combined	102 (9.4%)	6 (14.0%)	117 (14.9%)	12.07	225	**< 0.01**
	All delphinids combined	1,002(28.8%)	38 (29.5%)	558 (33.6%)	8.52	1,598	**< 0.02**
	White-beaked dolphin	232 (26.0%)	10 (30.3%)	107 (35.2%)	6.83	349	**< 0.05**
	Atlantic white-sided dolphin	209 (46.9%)	7 (43.8%)	105 (55.3%)	2.01	321	< 0.50
Feeding	All cetaceans combined	646 (10.6%)	23 (9.8%)	303 (9.1%)	5.08	972	< 0.10
	All delphinids combined	509 (14.6%)	15 (11.6%)	231 (13.9%)	1.09	755	< 0.70
Logging / resting	All cetaceans combined	140 (2.3%)	6 (2.6%)	107 (3.2%)	6.74	253	**< 0.05**

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited			χ^2	n	p-value
		Not active	Soft start	Full power			
Milling	All cetaceans combined	157 (2.6%)	7 (3.0%)	89 (2.7%)	0.18	253	< 0.95
Porpoising	All cetaceans combined	533 (8.8%)	27 (11.5%)	253 (7.6%)	6.28	813	**< 0.05**
	All delphinids combined	483 (13.9%)	23 (17.8%)	243 (14.6%)	1.65	749	< 0.20
	Atlantic white-sided dolphin	144 (32.3%)	5 (31.3%)	56 (29.5%)	0.34	205	< 0.90
Interactions with or travel towards vessel / equipment	All mysticetes combined	69 (6.3%)	1 (2.2%)	28 (3.6%)	7.52	98	**< 0.05**
	All delphinids combined	709 (20.4%)	18 (14.0%)	170 (10.2%)	68.76	897	**< 0.001**
	White-beaked dolphin	321 (36.0%)	8 (24.2%)	46 (15.1%)	32.66	375	**< 0.001**
Slow swimming	All cetaceans combined	987 (16.2%)	31 (13.2%)	576 (17.3%)	2.99	1,594	< 0.30
	All mysticetes combined	249 (22.8%)	3 (7.0%)	177 (22.5%)	4.66	429	< 0.10
	All delphinids combined	477 (13.7%)	16 (12.4%)	245 (14.8%)	1.10	738	< 0.70
	Minke whale	142 (23.8%)	0 (0.0%)	88 (25.0%)	6.68	230	**< 0.05**
Splashing	All delphinids combined	215 (6.2%)	10 (7.8%)	126 (7.6%)	3.56	351	< 0.20
Surfacing infrequently	All cetaceans combined	346 (5.7%)	11 (4.7%)	156 (4.7%)	4.34	513	< 0.20

Airguns: small arrays

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited			χ^2	n	p-value
		Not active	Soft start	Full power			
Breaching / jumping	All delphinids combined	140 (26.1%)	7 (36.8%)	49 (34.8%)	7.42	196	**< 0.05**
Fast swimming	All cetaceans combined	141 (14.0%)	9 (22.0%)	39 (15.7%)	1.95	189	< 0.50
Slow swimming	All cetaceans combined	150 (14.9%)	3 (7.3%)	30 (12.1%)	2.53	184	< 0.30

Behaviour	Species	Frequency (and %) of encounters when behaviour was exhibited			χ^2	n	p-value
		Not active	Soft start	Full power			
Interactions with or travel towards vessel / equipment	All delphinids combined	189 (35.2%)	4 (21.1%)	12 (8.5%)	27.50	205	**< 0.001**

Table 13. Occurrence of travel away from the vessel at different distance bands in relation to source activity (not active or soft start or full power), tested using the chi-squared test (n = number of sightings where animals were travelling away; d.f. = 2). Significant results are in bold.

Airguns: large arrays

Species	Distance band	Frequency (and %) of encounters when animals were travelling away from the vessel			χ^2	n	p-value
		Not active	Soft start	Full power			
All cetaceans combined	0–1,000 m	319 (9.2%)	25 (19.7%)	208 (14.2%)	32.18	552	**< 0.001**
	1,001–2,000 m	146 (15.7%)	13 (27.1%)	168 (21.0%)	8.44	327	**< 0.02**
	2,000–3,000 m	91 (17.7%)	8 (33.3%)	117 (28.7%)	13.19	216	**< 0.01**
	> 3,000 m	108 (19.4%)	3 (10.0%)	117 (23.4%)	3.83	228	< 0.20
All delphinids combined	0–2,000 m	220 (8.6%)	19 (18.8%)	176 (14.7%)	34.29	415	**< 0.001**
	> 2,000 m	105 (18.7%)	7 (25.9%)	97 (25.1%)	4.63	209	< 0.10

Alterations of course (for all cetaceans combined) were also recorded in a greater proportion of encounters when the source was active, particularly at full power (Table 12); 67% of alterations of course during the soft start were away from the vessel, compared to 32% at full power and 27% when the source was not active. Conversely, interactions with or travelling towards the vessel or its equipment were recorded more often when the source was not active for the combined groups of mysticetes and delphinids and for the white-beaked dolphin. In the case of mysticetes, such interactions were observed least often during the soft start, while for all delphinids and the white-beaked dolphin such interactions were observed least often at full power.

Some differences were also found in swimming and surfacing behaviour on surveys with large arrays of airguns (Table 12). Fast swimming (all mysticetes, all delphinids and white-beaked dolphins) was more prevalent when the source was active, particularly at full power. When all cetaceans were combined, porpoising was recorded more often during the soft start. Slow swimming was only found to differ significantly with source activity for minke whales, which were never recorded as swimming slowly during the soft start. Although only a small proportion of sightings were recorded as logging or resting at the surface, these behaviours occurred more often during sightings when the source was active, more so at full power than during the soft start. However, diving (all cetaceans combined) was also more prevalent when the source was active, with little difference in the occurrence of this behaviour between the soft start and full power.

On surveys with small arrays of airguns, delphinids were recorded as breaching or jumping more often when the airguns were active, with the highest incidence of breaching / jumping occurring during the soft start (Table 12). Interactions with or travel towards the vessel or its equipment by delphinids were recorded mostly when the airguns were not active, with such behaviours occurring least often when the airguns were firing at full power.

On surveys with large arrays of airguns there were 149 encounters with marine mammals that were initially detected when the source was not active but were still present when the soft start commenced. Of these, 15 (10%) displayed a change in behaviour that could be described as a startle response. A range of species exhibited startle responses; Atlantic white-sided dolphins displayed such responses most often (four occasions), but other species included white-beaked dolphin, sperm whale, fin whale, minke whale, long-finned pilot whale, killer whale, and common dolphin. The most common response was avoidance (e.g. by altering course) but other responses included diving, resurfacing, surfacing more often, increased speed, porpoising, leaping, spy-hopping, raising tail flukes / tail-slapping and subgroups joining together. There was one occasion when dolphins (*Lagenorhynchus* sp.) re-approached the vessel after initial avoidance, but they were observed spy-hopping, leaping and raising tail flukes. The distance that animals were at when a startle response was exhibited was not routinely recorded, but due to the requirements of the JNCC guidelines most would have been outside the 500 m mitigation zone around the airguns, although on one occasion a startle response was observed when a soft start commenced with long-finned pilot whales in the mitigation zone (due to a communication problem). The closest approach recorded throughout encounters showed that startle responses could sometimes occur at some distance from the source. For sperm whales, startle responses were recorded for one individual that approached no closer than 2 km and for another individual that approached no closer than 3 km.

On surveys with small arrays of airguns, there were 28 occasions when marine mammals were still present when the airguns commenced firing, including five occasions when high resolution sources were also used together with the airguns. On only one (4%) of these encounters was there a startle response, where Atlantic white-sided dolphins that had been approaching the vessel exhibited avoidance when the soft start commenced.

4 Discussion

4.1 Distribution of marine mammals

The distribution of marine mammal encounters during geophysical surveys largely reflected survey effort, which varied both spatially and temporally. Given this variation in effort, caution should be exercised when interpreting distribution maps. Furthermore, geophysical survey vessels do not present an unbiased platform, with the distribution of animals potentially being influenced by the operations. Nevertheless, observed differences in distribution between species mostly concurred with known distribution patterns.

Some cetacean species are known to occur in shelf edge and deep waters, particularly to the north-west of Britain. The location of encounters with large whales (blue whale, fin whale, sei whale, humpback whale, sperm whale) matched this known distribution (Skov *et al.* 1995; Pollock *et al.* 2000; Reid *et al.* 2003; CODA 2009; Hammond *et al.* 2021). Fin whales were occasionally found in shelf waters in the North Sea and in the St George's Channel, where occasional sightings have been recorded in other studies (Reid *et al.* 2003; ORCA 2016). Humpback whales were also occasionally encountered closer inshore to the east of Shetland, where records have been noted previously (Reid *et al.* 2003). The sightings of humpback whales in the Southern North Sea in 2012 concur with a relatively recent increase in sightings of this species in this region (Leopold *et al.* 2018). There were also a few encounters with sperm whales in the North Sea; that sperm whales do sometimes venture into the North Sea is evidenced by strandings on North Sea coasts (IJsseldijk *et al.* 2018b).

The probable North Atlantic right whale seen in 2000 must remain unconfirmed. At the time, the estimated population in the north-west Atlantic was 263–314 animals (IWC 2001) and there had only been eight confirmed sightings (comprising 11 individuals) in the north-east Atlantic since 1960 (Øien *et al.* 2001).

Long-finned pilot whales were also encountered predominantly in shelf edge and deep waters to the north and west of Britain and Ireland, with some encounters as far south as the South-west Approaches and some also recorded along the edge of the Rinne, agreeing with their known distribution (Skov *et al.* 1995; Pollock *et al.* 2000; Reid *et al.* 2003; CODA 2009; Rogan *et al.* 2018; Hammond *et al.* 2021). The decrease in sighting rates of long-finned pilot whales West of Shetland in 2006–2010 followed by an increase in 2011–2015 concurs with the results of NASS surveys between 1987 and 2015; Pike *et al.* (2019) found that long-finned pilot whale numbers declined until 2007 and then recovered to their highest levels in 2015. They found no significant or consistent trends in numbers of long-finned pilot whales but noted that changes in annual distribution clearly affected the results.

Beaked whales occur mainly in deep waters (CODA 2009; Hammond *et al.* 2021) as was the case here, although there were a few sightings of northern bottlenose whales in the North Sea including one close to the coast at Aberdeen. Occasional inshore sightings of this species are reported but often result in strandings (Grove *et al.* 2020), although in the case of the individual seen off Aberdeen no stranding nearby was subsequently reported (source: Scottish Marine Animal Stranding Scheme https://strandings.org/map/).

Atlantic white-sided dolphins were also frequently encountered in shelf edge and deep waters to the north and west of Britain, with additional encounters in shelf waters of the North Sea. This concurred with known distribution (Pollock *et al.* 2000; Reid *et al.* 2003; Hammond *et al.* 2021). Risso's dolphins were encountered mostly beyond the shelf edge, in contrast to other studies where they have been recorded mainly in shelf waters (Reid *et al.* 2003; Hammond *et al.* 2021). However, some were seen in shelf waters, including some in the Irish Sea, where they have also been recorded in other studies (Reid *et al.* 2003; Hammond *et al.* 2021).

The decrease in sightings of fin whales, sperm whales and Atlantic white-sided dolphins to the West of Shetland after 2005 is unexplained. Although season, source activity, weather conditions and monitoring method were controlled for when comparing sighting rates between five-year periods, fine scale variation in location was not controlled for as sighting rates were calculated over broad regions. It is possible that the precise locations of surveys within the West of Shetland area varied sufficiently between years to account for differences in sighting rates.

Killer whales are more abundant in high latitude waters (Forney & Wade 2006); they show strong inter-annual site fidelity but make seasonal movements including movements between Scotland and Iceland (Foote *et al.* 2010; Samarra & Foote 2015). Most killer whales encountered during geophysical surveys were in northern areas, with a particular concentration to the north-east of Shetland. Reid *et al.* (2003) noted some sightings around the Rinne; encounters in this area were also evident during geophysical surveys, together with other scattered encounters in shelf waters of the Northern North Sea. The single sighting of false killer whales occurred to the west of Ireland in a similar location to a sighting reported by Reid *et al.* (2003).

In contrast to many other species, white-beaked dolphins were found primarily in shelf waters of the Central and Northern North Sea, in accordance with their known distribution (Northridge *et al.* 1995; Reid *et al.* 2003; Hammond *et al.* 2013, 2021). White-beaked dolphins have been shown to prefer shallower waters (MacLeod *et al.* 2007) but during geophysical surveys they were also found in deeper waters beyond the shelf edge. IJsseldijk *et al.* (2018a) found that strandings of white-beaked dolphins in the southern North Sea decreased between 1991 and 2017 while those further north increased slightly; they suggested that there had been northwards shift in the species' distribution. No evidence of a northwards shift was apparent from geophysical survey data, with the only consistent trend being a decline in sighting rates in the Outer Moray Firth. The SCANS-III survey also found no evidence of a change in distribution of white-beaked dolphins (Hammond *et al.* 2021).

Around the UK, common dolphins and striped dolphins are both known to have a distribution centred more to the south-west (Reid *et al.* 2003; CODA 2009; Hammond *et al.* 2021). However, survey effort on geophysical surveys was relatively low in south-western areas. Although common dolphins were encountered in the St George's Channel and the South-west Approaches, due to greater survey effort similar numbers were encountered further north, extending as far as the North of Shetland. The range of common dolphins has been predicted to extend northwards with rising temperatures (Lambert *et al.* 2011). During geophysical surveys more common dolphins were encountered in the North Sea than have been found in some other studies (Reid *et al.* 2003; Hammond *et al.* 2021), although Robinson *et al.* (2010) noted sightings of this species in the Moray Firth from 2006 onwards. For striped dolphins it is perhaps surprising that, although survey effort in the South-west Approaches was low, none were encountered in that area. Instead, highest numbers of striped dolphins were encountered in deep waters to the West and North of Shetland. There were occasional sightings of striped dolphins in the North Sea, like occasional records reported elsewhere (ORCA 2016).

Other species were more widespread in UK waters. Minke whales were widespread both in shelf waters and over the shelf edge and deeper waters, with concentrations to the West of Shetland and in the Central North Sea. Some occurred closer inshore, as has been recorded previously (Northridge *et al.* 1995; Reid *et al.* 2003). The SCANS and SCANS-II surveys found weak evidence of a southwards shift in minke whale distribution in the North Sea between 1994 and 2005, with the observed distribution during SCANS-III in 2016 remaining similar to that observed in 2005 (Hammond *et al.* 2013, 2021). The increase in sighting rates of minke whales during geophysical surveys in the Southern North Sea after 2005 would fit with a southwards shift.

Bottlenose dolphins encountered during geophysical surveys were also widespread, with encounters both to the west of Britain and in the North Sea. Other studies have recorded bottlenose dolphins more often to the west of Britain with those in the North Sea being mainly in inshore waters off north-east Scotland (Reid *et al.* 2003; Hammond *et al.* 2021). As well as being found in inshore waters around Scotland, bottlenose dolphins encountered during geophysical surveys were found in shelf waters throughout the North Sea and in deeper waters further offshore to the west and north of Britain.

The harbour porpoise is one of the most abundant cetaceans in European Atlantic waters (Hammond *et al.* 2021) but was recorded less often than some other species on geophysical surveys. This is likely to be due, at least in part, to difficulty in detecting harbour porpoises in increased sea states above sea state 2 (Hammond *et al.* 2013). The harbour porpoise has a widespread distribution in UK waters (Reid *et al.* 2003; Hammond *et al.* 2013, 2021); while some were encountered during geophysical surveys to the west of Britain, more were encountered in the North Sea due to increased survey effort. The decadal-scale SCANS, SCANS-II and SCANS-III surveys found no evidence for a change in population size but did find southwards shift in distribution between 1994 and 2005 that was maintained in 2016, also extending into the English Channel by that time (Hammond *et al.* 2013, 2021). This southwards shift has also been evidenced in annual surveys (Peschko *et al.* 2016). Harbour porpoise sighting rates during geophysical surveys in the Southern North Sea increased between 2006 and 2015, in line with southwards shift in distribution, but declined again in that area after 2015. However, sighting rates in the Northern North Sea did not show a corresponding consistent decrease. Although a decline in sighting rates in the Northern North Sea in 2006–2010 was reported previously (Stone 2015a), the addition of a further 10 years of data shows that this decline was not sustained. No harbour porpoises were encountered in the English Channel, but survey effort in that area was low.

Both grey and harbour seals had a similar distribution, but grey seals were seen more often. Although grey seals were seen further offshore to the West of Shetland than harbour seals, both species were seen at similar distances from land in the North Sea. Sharples *et al.* (2012) found that tagged harbour seals made wide-ranging movements to sea but there were regional differences, with Shetland being amongst the regions where foraging trips were shorter in terms of both distance and duration.

4.2 Effect of geophysical operations on marine mammals

Cetaceans, as marine European Protected Species (EPS), are protected under UK law by a series of regulations: the Conservation of Habitats and Species Regulations 2017, the Conservation of Offshore Marine Habitats and Species Regulations 2017 and similar legislation for Northern Irish and Scottish inshore waters. These regulations prohibit deliberate injury and disturbance of EPS. Disturbance in this context includes disturbance that is likely to impair the animals' ability to survive, to breed or reproduce, or to rear or nurture their young, or to migrate, or disturbance that will significantly affect their local distribution or abundance. Behavioural responses may be indicative of disturbance and may be ranked using a severity scale developed by Southall *et al.* (2021). This scale evaluates observed behavioural responses of free-ranging marine mammals to anthropogenic sound using three parallel tracks for responses related to survival (including effects on defence, resting, social interactions and navigation), foraging (including search, pursuit, capture, and consumption) and reproduction (including mating and parenting behaviours). Responses are scored from zero (no detected response) to nine (risk that behavioural response leads to serious injury or mortality, or disruption of energetic balance sufficient to result in morbidity or mortality, or failure to successfully reproduce during the breeding season).

Lateral displacement in response to activity of large arrays of airguns was evidenced in some species by reduced detection rates and/or animals remaining further from the source when it was active. Where detection rates were reduced this suggests lateral displacement beyond the range of visual or acoustic detection. Reduced detection rates when the source was active were found for a range of species: grey seal, minke whale, killer whale, white-beaked dolphin, Atlantic white-sided dolphin, common dolphin, and harbour porpoise. Reduced detection rates have been demonstrated for these species previously, except for common dolphins, which in earlier studies were only found to swim at increased speed (Stone 2015a; Stone *et al.* 2017). For all these species except grey seals, which are difficult to detect at a distance, those that were detected when the source was active were found to remain further away; similar results have also been found in the Gulf of Mexico and West Africa (Barkaszi *et al.* 2012; Barkaszi & Kelly 2019; Milne *et al.* 2019). Where animals remained further from the source, but detection rates were not reduced, this indicates lateral displacement of a lesser degree, i.e. not beyond the visual / acoustic detection range. This was the case for bottlenose dolphins in response to firing of large arrays of airguns. The onset of avoidance, including increased range from the source, is given a rank score of five on Southall *et al.*'s (2021) severity scale for behavioural changes affecting survival. This is increased to six if the avoidance is sustained, however in the case of geophysical surveys, movement of both the animals and the vessel mean that encounters are typically brief and furthermore there is no information beyond the duration of the survey, so sustained avoidance cannot easily be demonstrated. Given that many of the higher detection rates / closer approaches found during periods of inactivity would have occurred between survey lines and therefore shortly after a period of activity, it is likely that avoidance was not sustained. A possible exception to this is the harbour porpoise where, in addition to detection rates being reduced during periods of activity throughout surveys, detection rates regardless of source activity were reduced after operations commenced.

Many of the species that had reduced detection rates and remained further from large arrays of airguns during periods of activity also demonstrated other behavioural responses at these times, such as avoidance / travel away from the vessel, alterations of course, or fewer instances of interacting with / travelling towards the vessel or its equipment. Long-finned pilot whales, which showed no evidence of lateral displacement, also exhibited these behavioural responses, demonstrating localised avoidance.

As well as horizontal avoidance of noise there could also be vertical avoidance. Long-finned pilot whales were observed to dive more often when large arrays of airguns were active. A detectable change in diving behaviour is given a score of one on Southall *et al.*'s (2021) severity scale of behavioural changes affecting survival. In contrast, there were indications that other species remained closer to the surface when large arrays of airguns were active. The combined groups of all cetaceans and all mysticetes were recorded more often as surfacing frequently (and similarly recorded less often as surfacing infrequently) when the airguns were active. The group of all cetaceans were also recorded as logging or resting at the surface more often at these times. Although some other studies have found that cetaceans may remain submerged during seismic operations (Gailey *et al.* 2007; Robertson *et al.* 2013), more have found evidence of animals remaining near the surface in response to noise. McCauley *et al.* (1998, 2000) found that humpback whales spent more time at the surface during periods of seismic operations; Jochens *et al.* (2008) and Miller *et al.* (2009) suggested that a sperm whale responded to airgun sounds by resting near the surface until airgun exposure ceased; Milne *et al.* (2019) found a trend towards more surface-active behaviours in delphinids when airguns were at full power. It is possible that animals may be staying close to the surface because levels of sound there may be reduced due to the Lloyd mirror effect, where there is interference between sound on a direct path from the source and surface reflections (Urick 1983; Richardson *et al.* 1995). Changes in surfacing / diving patterns in response to noise may have implications for foraging success, if for example, deep foraging dives are curtailed (Friedlaender *et al.* 2020).

When all cetaceans were combined, there was a small but significant decrease in the occurrence of feeding when large arrays of airguns were active. A detectable interruption of foraging behaviour is ranked as one on Southall *et al.*'s (2021) severity scale of behavioural changes affecting feeding. However, increased energetic expenditure, for example from an increased swimming speed, is given a score of four. Several cetacean species (minke whale, bottlenose dolphin and white-beaked dolphin), as well as the combined group of seals, were recorded as swimming fast more often when large arrays of airguns were active. Only one species, the long-finned pilot whale, was recorded as swimming slowly more often when the airguns were active.

Although there were fewer responses to activity of small arrays of airguns, some responses were nevertheless evident. Lateral displacement beyond the visual / acoustic detection range was indicated for the minke whale, sperm whale and harbour porpoise. Displacement of sperm whales and harbour porpoises by small arrays of airguns had been noted previously (Stone 2015a; Stone *et al.* 2017) but examination of the larger dataset revealed that minke whales were also displaced. Interactions with or travel towards the vessel or its equipment were reduced for delphinids and Atlantic white-sided dolphins, indicating some level of localised avoidance. There was some evidence of surface / aerial behaviours, with cetaceans (all species combined) being recorded as breaching, jumping or splashing more often when the airguns were active. Effects on surfacing were inconclusive though, as cetaceans were recorded as both surfacing frequently and surfacing infrequently more often when small arrays of airguns were active.

This analysis includes for the first-time examination of responses to high resolution sources such as sub-bottom profilers. However, data from high resolution surveys were mostly collected from 2014 onwards and these surveys are typically short in duration, so there were relatively few marine mammal encounters available for analysis. Furthermore, high resolution sources are often used in combination, so data were limited for individual sources. Species had to be combined to increase sample sizes and only pingers and chirps were able to be examined. Nevertheless, for the combined group of all cetaceans, detection rates were reduced when pingers were active and animals remained further from the source when chirps were active. Both responses indicate some degree of lateral displacement. Further data are needed to examine responses of marine mammals to high resolution sources in more detail, but these preliminary results confirm that mitigation should continue to be applied on high resolution surveys.

Marine mammals have been divided into functional hearing groups based on their ability to hear at different frequencies (Southall *et al.* 2007, 2019); it might be expected that there would be a similarity in behavioural responses to sound within these groups. Mysticetes are placed in the low frequency cetaceans hearing group, with hearing estimated to be within the range 10 Hz to 34 kHz (Southall *et al.* 2019). Their hearing range makes them vulnerable to injury (e.g. temporary or permanent threshold shift) and disturbance from the low frequency sound produced by airguns, where peak energy is at frequencies up to about 200 Hz (Landrø & Amundsen 2018). In UK waters, lateral displacement of minke whales has been demonstrated previously for large arrays of airguns (Stone 2015a; Stone *et al.* 2017), but the addition of more data revealed displacement with small arrays also. Localised avoidance of active airguns by minke whales has also been observed in the northwest Atlantic (Moulton & Holst 2010). In the current study, while some responses were observed for the combined group of all mysticetes as well as for minke whales, other individual mysticete species showed no response. Previous analysis of UK MMO data found some evidence of localised avoidance of large arrays of airguns by fin whales (Stone 2015a; Stone *et al.* 2017) but the addition of a further 10 years of data resulted in this response being no longer detectable. Fin whales in the Mediterranean Sea were found to modify their vocalisations and move out of the area of a seismic survey for an extended period (Castellote *et al.* 2012). Elsewhere responses to seismic survey vessels have been demonstrated for humpback whales (McCauley *et al.* 1998, 2000; Moulton & Holst 2010; Dunlop *et al.* 2013, 2017, 2018; Cerchio *et al.* 2014); sample sizes were mostly too low to examine the response of humpback whales in UK waters, but where there were sufficient data, no responses were observed. Avoidance of seismic survey vessels has also been demonstrated elsewhere for other mysticetes such as bowhead whales and gray whales (e.g. Richardson *et al.* 1986, 1999; Ljungblad *et al.* 1988; Richardson & Greene 1993; Yazvenko *et al.* 2007), although some studies have found no responses of mysticetes attributable to source activity (Bröker *et al.* 2015; Muir *et al.* 2015; Gailey *et al.* 2016; Vilela *et al.* 2016).

Most odontocetes belong to a high frequency hearing group with functional hearing in the range 40 Hz to 169 kHz (Southall *et al.* 2019). Although sound from seismic airguns is predominantly low frequency, higher frequency sounds are also emitted that would be audible to odontocetes (Goold & Fish 1998; De Ruiter *et al.* 2006; Madsen *et al.* 2006; Potter *et al.* 2007; Hermanssen *et al.* 2015; Kyhn *et al.* 2019). Potter *et al.* (2007) noted that these high frequency sounds are likely to attenuate rapidly, although Kyhn *et al.* (2019) found noticeable energy at high frequencies up to 14 km away from the source and considered that behavioural effects may occur in high frequency species well beyond the visual range of observers. Overall, more responses in this study were observed in the high frequency hearing group than in the low frequency group, as has been found previously for UK waters (e.g. Stone & Tasker 2006) and elsewhere (Weir 2008a; Barkaszi & Kelly 2019; Kavanagh *et al.* 2019). In UK waters, the high frequency cetacean hearing group includes delphinids, the sperm whale and beaked whales; in this study responses were often noted in delphinids. Where sample sizes were sufficient to test, all delphinid species except Risso's dolphin (for which sample sizes were small) showed some behavioural response to activity of large arrays of airguns, although the degree of response was lower for long-finned pilot whales than for other delphinids.

Sperm whales showed no response to large arrays of airguns but did show displacement from small arrays although there was no apparent reason why they would respond only to the smaller sources. Mixed results have been found for sperm whales in studies in the Gulf of Mexico: Winsor *et al.* (2017) found no evidence of horizontal avoidance of active airguns, but Barkaszi and Kelly (2019) found that sperm whales remained further from the airguns when they were at full power than when they were not active. Other studies in the Gulf of Mexico (Jochens *et al.* 2008; Miller *et al.* 2009) indicated that sperm whales may respond to airgun operations by remaining at the surface; however, such behaviour would make them more easily detectable by visual observers, which may falsely inflate detection rates compared to periods when the airguns are not active. In the present study there were no indications that sperm whales were remaining closer to the surface during periods when large arrays of airguns were active.

Beaked whales showed no responses to geophysical surveys in the present study. Sample sizes for beaked whales were small; although previous analysis of UK MMO data did find that detection rates of beaked whales were reduced in response to activity of large arrays of airguns (Stone 2015a; Stone *et al.* 2017) this was no longer evident in this longer study. Analyses of MMO data from Canada and the Gulf of Mexico have similarly found no evidence of avoidance of active airguns by beaked whales (Moulton & Holst 2010; Barkaszi & Kelly 2019). However, a lack of observed response does not mean that beaked whales are not impacted by noise and a lack of avoidance could result in increased exposure. Beaked whales are known to be sensitive to anthropogenic noise, with cases of mass strandings following the use of military mid-range frequency sonar (Balcomb & Claridge 2001; Evans & England 2001; Fernández *et al.* 2005; Cox *et al.* 2006; Tyack *et al.* 2011).

The harbour porpoise belongs to the very high frequency cetacean hearing group and is the only regularly occurring species within this group in UK waters. This hearing group has functional hearing between 200 Hz and 220 kHz and is recognised as being more sensitive to auditory effects of noise exposure than the other hearing groups (Southall *et al.* 2019). Harbour porpoises showed lateral displacement beyond the visual / acoustic detection range when airguns (both large arrays and small arrays) were active; furthermore, they were the only species to show a decline in detection rates after the commencement of operations. Other studies have similarly found harbour porpoises to be more sensitive to geophysical surveys than other species. Lucke *et al.* (2009) found aversive behavioural responses of a single captive harbour porpoise when exposed to noise from a seismic airgun and found that the masked temporary threshold shift level was lower than for other odontocetes. Bain and Williams (2006) found that harbour porpoises appeared to be the species affected by the lowest levels of airgun noise, with apparent avoidance over 70km from airguns, although sample sizes were too small to permit statistical testing. However, other studies, whilst showing short-term disturbance, found no evidence of long-term displacement. Thompson *et al.* (2013b) found that seismic operations using a relatively small array (470 cu.in.) resulted in short-term avoidance by harbour porpoises, with animals typically detected again at affected sites within a few hours; there were indications of possible habituation or tolerance as the survey progressed. However, those porpoises remaining in the area did reduce their buzzing activity (indicative of prey capture or social communication) with the probability of buzzes decreasing with proximity to the source (Pirotta *et al.* 2014). Sarnocińska *et al.* (2020) also found a decrease in harbour porpoise echolocation signals up to 8–12km from active airguns, indicating either temporary displacement or a change in echolocation behaviour, but found no evidence of long-term or large-scale displacement. Van Beest *et al.* (2018) found that noise-induced movement in harbour porpoises exposed to a single 10 cu.in. airgun in a controlled exposure experiment typically lasted up to eight hours, with an additional 24-hour recovery period before normal behaviour was resumed. However, during a typical seismic survey in the UK, periods of activity are often spaced less than 24 hours apart, potentially not allowing time for recovery of normal behaviour until completion of the survey. Wisniewska *et al.* (2016) considered that the almost continuous foraging requirements of harbour porpoises made them vulnerable to anthropogenic disturbance, with even moderate levels of disturbance potentially having severe fitness consequences at individual and population levels.

Pinniped species in the phocid carnivore hearing group have functional hearing between 75 Hz and 100 kHz (Southall *et al.* 2019); both the grey seal and harbour seal belong to this group. Seals showed some responses to surveys with large arrays of airguns, with lateral displacement of grey seals beyond the visual / acoustic detection range and localised avoidance and faster swim speeds being observed for the group of all seals combined. No responses were evident for the harbour seal as an individual species. Relatively few studies have examined responses of pinnipeds to geophysical surveys. Lalas and McConnell (2016) found that New Zealand fur seals responded to the presence of the vessel and its towed gear but could not demonstrate a response to airgun activity, but Harris *et al.* (2001) found there was avoidance of active airguns by seals (mostly ringed seals). Kvadsheim *et al.* (2010) found that hooded seals exposed to sonar had an increased heart rate and demonstrated learned behaviour, keeping their heads above water. Such behaviours may render seals more visible and thus affect detection rates, although no significant changes in surfacing behaviour of seals in UK waters in response to airgun activity (other than faster swimming speeds when large arrays were active) were observed.

Previous analysis of UK MMO data revealed that marine mammal detection rates were reduced during the soft start compared to when airguns were not active, but sample sizes at that time were only sufficient to test combined species groups and a few individual species; furthermore, all airgun arrays had to be examined together, regardless of size (Stone 2015a; Stone *et al.* 2017). The addition of more data in this analysis allowed large arrays and small arrays to be considered separately and, in the case of large arrays, for more individual species to be examined. All species tested for large arrays (grey seal, minke whale, sperm whale, long-finned pilot whale, killer whale, bottlenose dolphin, white-beaked dolphin, Atlantic white-sided dolphin, and harbour porpoise) had lower detection rates during the soft start than when the airguns were not active. Of those animals that were detected during the soft start of large arrays, the harbour porpoise was the only species that was found further from the airguns than when they were not active. The fact that mysticetes and delphinids became closer to the source during the soft start period then were ultimately further away than they were initially likely the result of movement of the vessel rather than intentional movement of the animals. This may indicate a degree of tolerance; given the slow speed of seismic survey vessels (typically around 4.5 knots) it is unlikely that marine mammals would be unable to move away if they wanted to. Nevertheless, some behaviours that were more prevalent at full power than when airguns were not active were also evident during the soft start (e.g. avoidance / travel away from the vessel, alterations of course, fast swimming, diving, reduced interactions with / travel towards the vessel or its equipment) and startle responses were also observed on some occasions. Porpoising was more prevalent during the soft start than at any other time on surveys with large arrays of airguns. Studies elsewhere have also recorded responses to the soft start of large arrays of airguns. Off West Africa, Milne *et al.* (2019) found that mysticetes and delphinids remained further from the airguns during the soft start compared to airgun silence and Weir (2008b) described avoidance by short-finned pilot whales. In the Gulf of Mexico, Barkaszi and Kelly (2019) found that blackfish (short-finned pilot whales, killer whales, false killer whales, melon-headed whales and pygmy killer whales) were further from the airguns during the soft start compared to when the airguns were not active, and Milne *et al.* (2019) found the same for sperm whales.

Although it was possible in the present study to examine the response of marine mammals to soft starts of small arrays of airguns, data were limited. Nevertheless, the combined groups of all cetaceans and all delphinids were found to have lower detection rates during the soft start than when the airguns were not active. Of those delphinids that were present during the soft start of small arrays, more were likely to be breaching / jumping than at other times. Dunlop *et al.* (2016b) found that humpback whales increased their distance from the source during the soft start of a small (440 cu.in.) airgun array, but the response was not more marked than with a constant source and there was some evidence of a response to the presence of the source vessel.

The data here suggest that there is some degree of avoidance or displacement during the soft start, meaning that it may to some extent achieve its aim of moving animals away before full power levels are reached, thereby reducing the risk of injury. However, not all animals did move away; although the proportion of sightings travelling away from the vessel during the soft start within a few kilometres of large arrays of airguns was approximately double that when the airguns were not active, it was still a minority of occasions when animals were moving away. Thus, the soft start may be effective for some animals but not all. Dunlop *et al.* (2016b) similarly found that the soft start was not completely effective at deterring humpback whales. Wensveen *et al.* (2017), considering the soft start of sonar, suggested that its effectiveness may depend on context, being more effective if animals have not been exposed to sound recently, are not engaged in feeding, or if a small calf is present. Given that there is not a universal response to the soft start it is important to continue using the primary mitigation measure of monitoring for marine mammals and delaying commencement of operations for any animals detected in the mitigation zone. However, conducting a soft start is still beneficial, as commencing at lower sound levels should reduce the risk of injury to nearby animals that have escaped detection and at least some undetected animals within 2–3km of the source may move away before full power is reached. Noise reduction should also be encouraged, for example by using alternative techniques such as marine vibroseis, which produces lower sound pressure levels and sound exposure levels and therefore reduces the potential for injury (Matthews *et al.* 2021). However, while marine vibroseis has the potential to reduce the risk of injury, signal durations are longer and may lead to increased masking, so the potential for behavioural impacts may remain. Matthews *et al.* (2021) modelled the risk to marine mammals from marine vibroseis and airguns and found that predicted behavioural disturbance could be more for either source depending on the criteria used.

MMO data are a useful resource for examining short-term responses of marine mammals to anthropogenic noise. However, there are limitations as long-term effects beyond the duration of surveys cannot be assessed and data prior to commencement are limited in duration. Although reduced detection rates may indicate lateral displacement beyond the visual / acoustic detection range, there is no knowledge of the full extent of this displacement and whether it results in changes in distribution significantly different from natural variation, which might be considered a disturbance offence under UK regulations (JNCC 2010). Observed behavioural changes are limited to those within the range of detection, with no information regarding behavioural changes beyond this range. For example, Heide-Jørgensen *et al.* (2021) found that tagged narwhals showed avoidance reactions at distances of up to 11km from active airguns, a distance where behaviour would not be able to be observed by MMOs. Furthermore, comparisons within geophysical surveys mean that much of the data collected during periods of inactivity will be during line changes and therefore not long after a period of activity. Kavanagh *et al.* (2019) found that sightings of mysticetes were not reduced during periods of activity within seismic surveys but were reduced when compared to control surveys; they argued that periods of inactivity within surveys cannot be considered representative of baseline conditions and should not be used as a control when assessing impacts of seismic surveys. Nevertheless, in the absence of baseline / control surveys, MMO data within surveys provides a valuable opportunity for examining short-term responses.

Although some short-term behavioural responses were found for some species and some sources, a lack of observed response in other cases does not necessarily imply that animals are not affected (Thomsen *et al.* 2011). Responses may vary depending on context, for example activity state (Ellison *et al.* 2011). Dunlop *et al.* (2016a) attributed a difference in avoidance reactions of humpback whales to the social context of the group. Robertson *et al.* (2013) found that changes in surfacing, respiration and dive behaviours in bowhead whales were context-dependent, depending on the circumstance and the activity of the animal; seismic operations had a greater effect when whales were travelling than when they were socialising or feeding. Changes in surfacing patterns may affect the ability to detect marine mammals and influence detection rates, potentially masking changes in abundance of animals (Robertson *et al.* 2013). As most of the detections in this study were visual, acoustic responses to sound (e.g. Castellote *et al.* 2012; Cerchio *et al.* 2014; Blackwell *et al.* 2015) may not have been readily apparent. Furthermore, there may be responses not detectable by either visual or acoustic means, for example an increase in the production of stress hormones, which has been demonstrated in response to exposure to anthropogenic sound in some cetaceans (Romano *et al.* 2004; Rolland *et al.* 2012; Yang *et al.* 2021). There could also be indirect effects, for example if prey species are impacted; McCauley *et al.* (2017) found a decrease in zooplankton abundance and an increase in the proportion of dead zooplankton following exposure to sound from airguns. Therefore, it is important that mitigation measures continue to be implemented for all marine mammal species and that work towards noise reduction / abatement continues.

5 Conclusions

Analysis of a 25-year dataset makes this the longest-term study of MMO data to date. Responses of marine mammals to active sources during geophysical surveys included lateral displacement, sometimes beyond the range of visual / acoustic detection, more localised avoidance and changes in swimming and surfacing behaviour. Responses varied between species but were observed in all marine mammal functional hearing groups represented in UK waters. Amongst the low frequency cetaceans, minke whales responded to both large arrays and small arrays of airguns. Amongst the high frequency cetaceans delphinids (except Risso's dolphin) responded to active airguns, mainly to large arrays, while sperm whales responded to small arrays of airguns. The harbour porpoise, the UK's only regularly occurring very high frequency cetacean, appeared to be the most sensitive of the species examined, responding to both large arrays and small arrays of airguns and being the only species to show an overall decline in detections after operations using large arrays commenced. In the phocid pinniped group, grey seals responded to large arrays of airguns. Although responses to small arrays of airguns were generally less evident than to large arrays, displacement was indicated for minke whales, sperm whales and harbour porpoises. High resolution sources were examined for the first time; while there was some evidence of avoidance of active sources (pingers and chirps), there is a need for more data to examine responses for individual species. The results confirm the importance of applying mitigation to all geophysical acoustic sources and for all marine mammals.

While results largely concurred with previous analysis of UK MMO data (Stone 2015a; Stone *et al.* 2017), the addition of 10 years of data did reveal some further responses. Minke whales were shown to respond to small arrays of airguns as well as large arrays and the response of common dolphins to large arrays was greater than found previously. Conversely, the addition of more data resulted in responses to large arrays of airguns previously found for beaked whales and fin whales being no longer detectable.

More data was available for examining responses to the soft start than previously, allowing for responses of more individual species to be examined and for large arrays and small arrays of airguns to be examined separately. There was evidence of some degree of displacement or avoidance during the soft start for both large arrays and small arrays of airguns. However, not all animals did display such responses so monitoring and delays for marine mammals in the mitigation zone should continue to be applied.

MMO and PAM data have limitations. For example, while the results of this analysis suggest that harbour porpoises may be displaced from the vicinity of seismic surveys while they are underway, the data are not able to determine the extent of exclusion from available habitat, such as might be required for assessment of disturbance within Marine Protected Areas (JNCC 2020). Nevertheless, the data have value in determining short-term, small-scale effects that, although they may not be significant for individual geophysical surveys, should be considered in the context of cumulative effects from multiple surveys or multiple stressors over wider spatial or longer temporal scales.

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Appendix 1 - Species maps

On all maps the short, dashed line = 200 m isobath; the long dashed line = 1,000 m isobath. Species maps show the number of individuals per licensing block (10' latitude x 12' longitude); for species where fewer than 15 individuals were seen, locations of sightings are plotted.

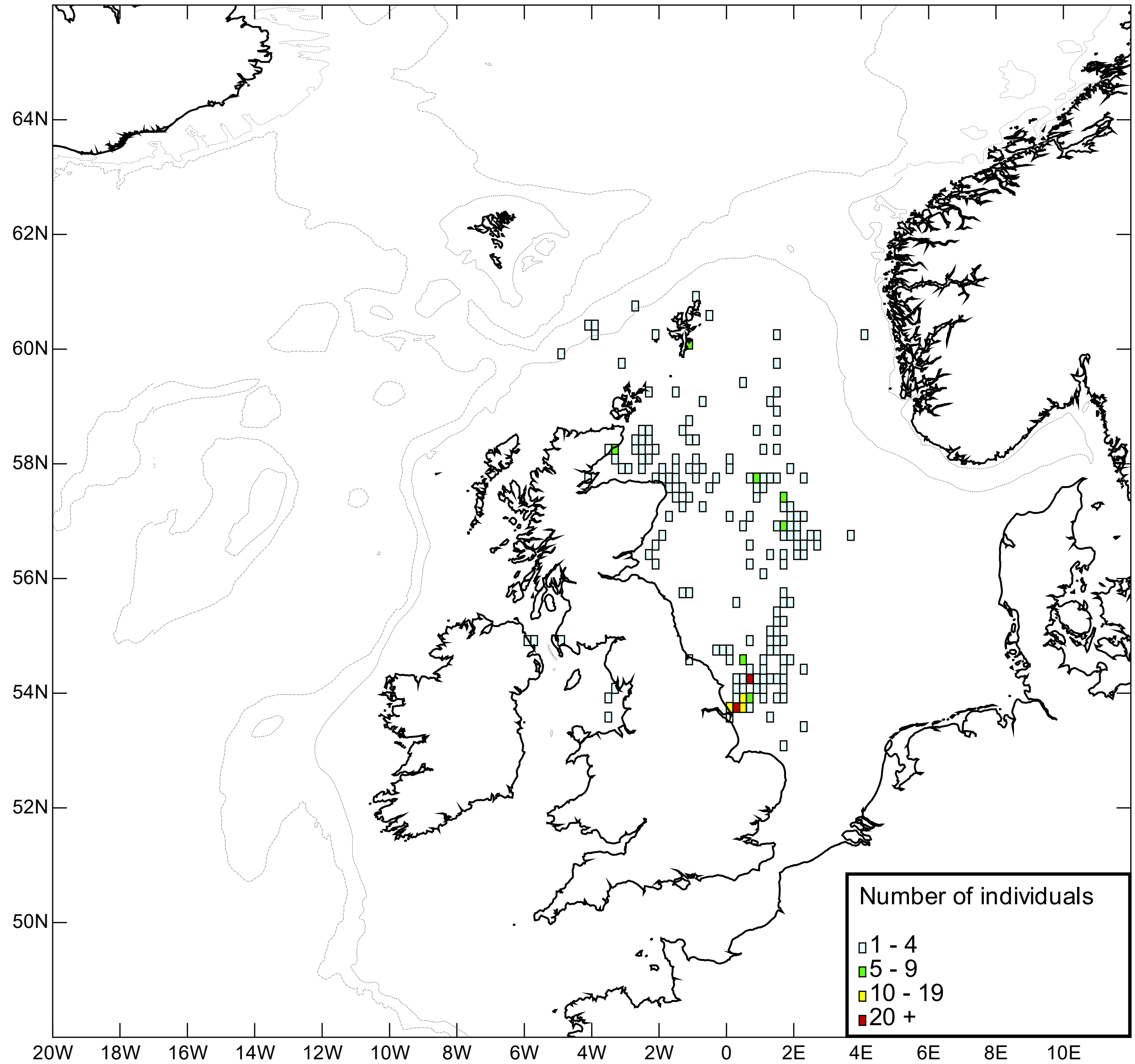

Figure 12. Grey seals encountered during geophysical surveys, 1995–2020.

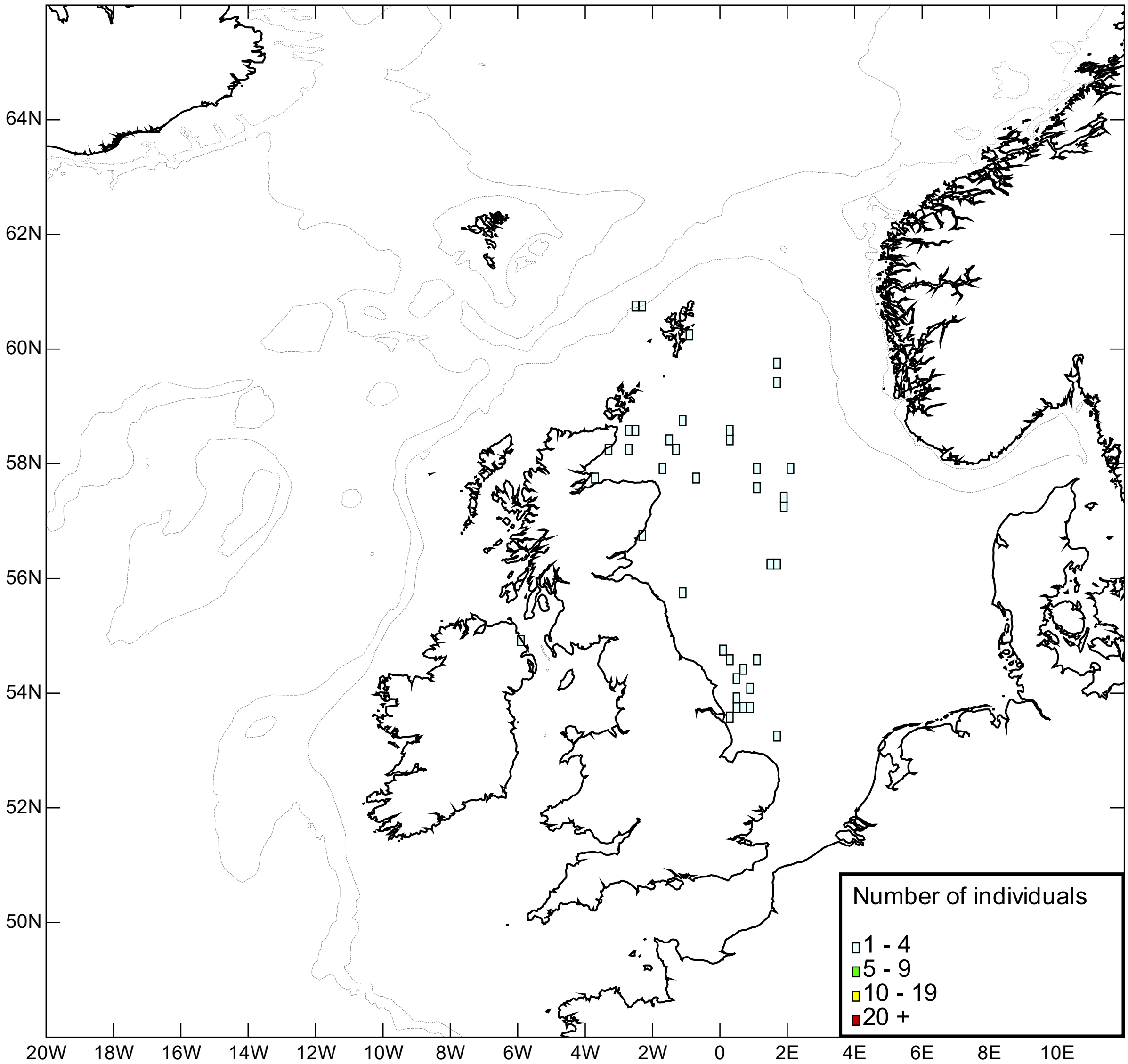

Figure 13. Harbour seals encountered during geophysical surveys, 1995–2020.

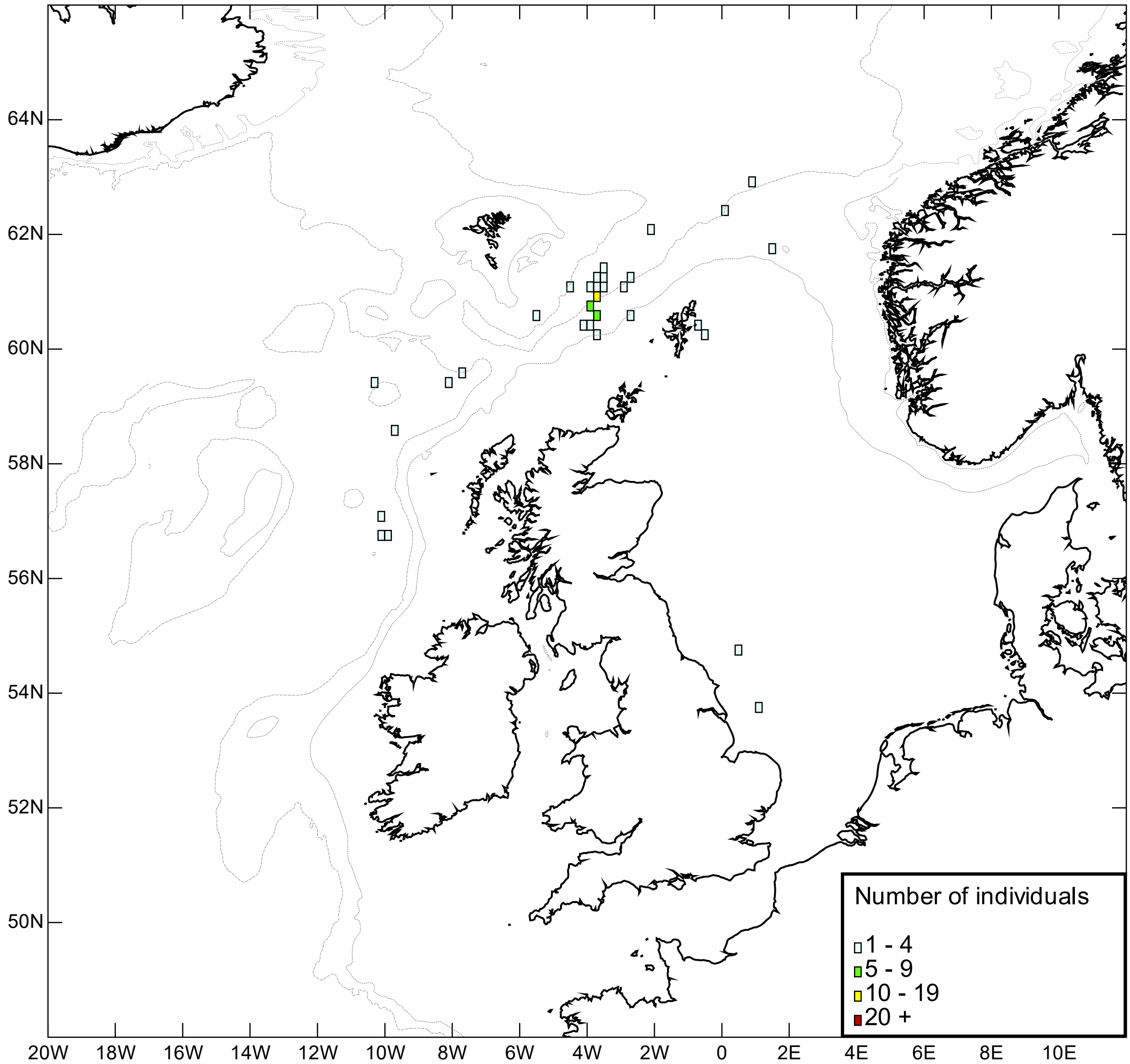

Figure 14. Humpback whales encountered during geophysical surveys, 1995–2020.

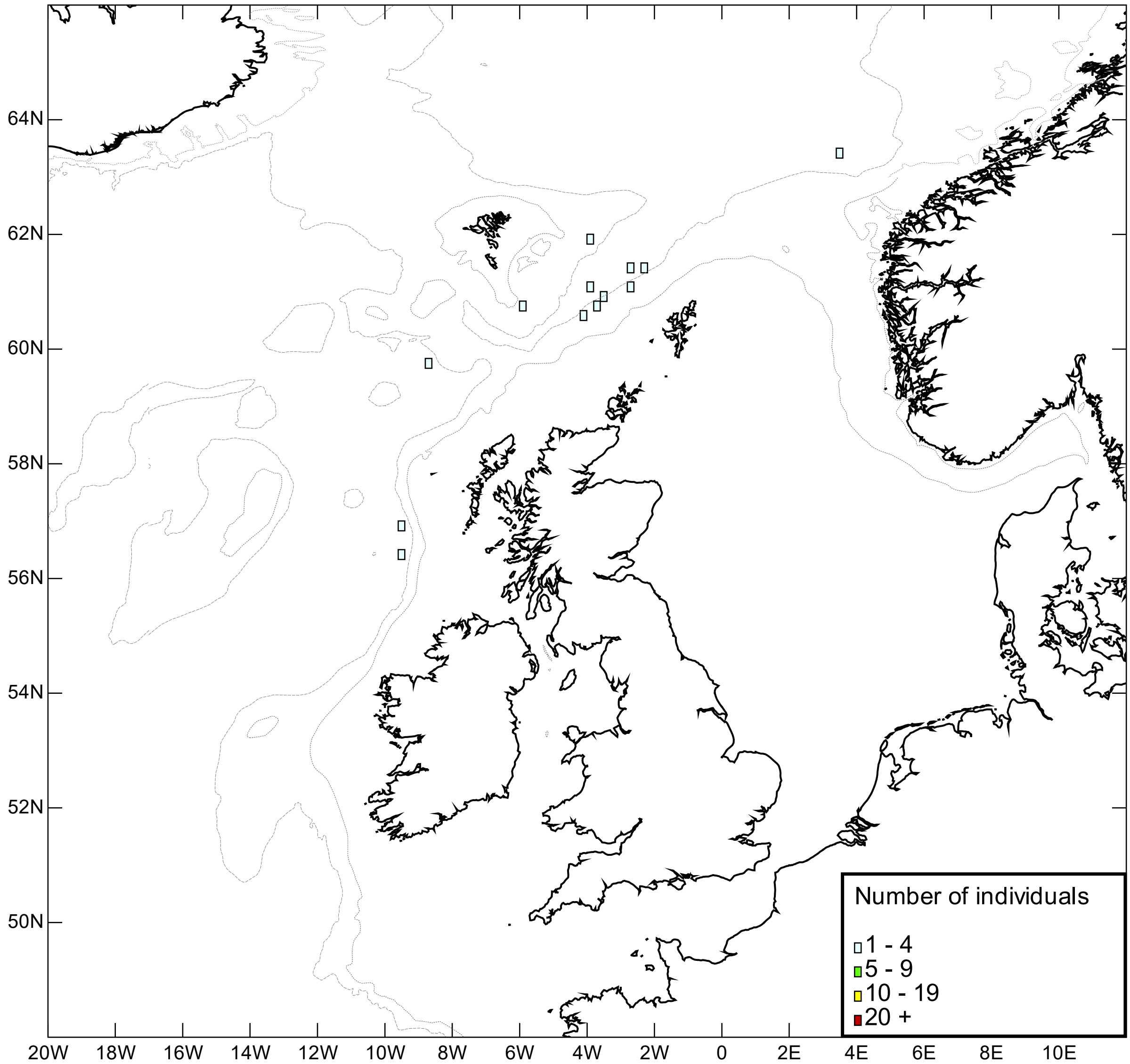

Figure 15. Blue whales encountered during geophysical surveys, 1995–2020.

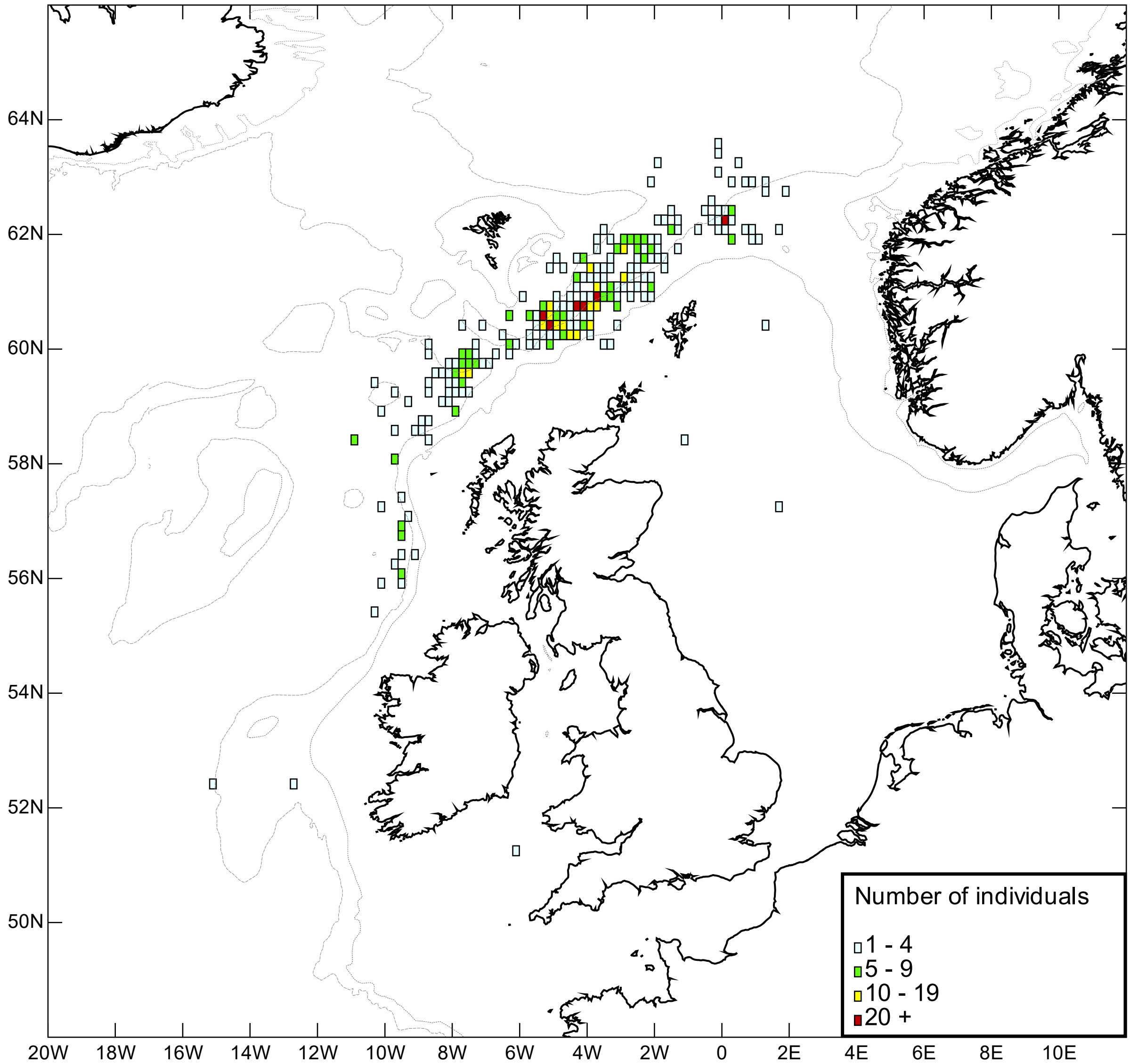

Figure 16. Fin whales encountered during geophysical surveys, 1995–2020.

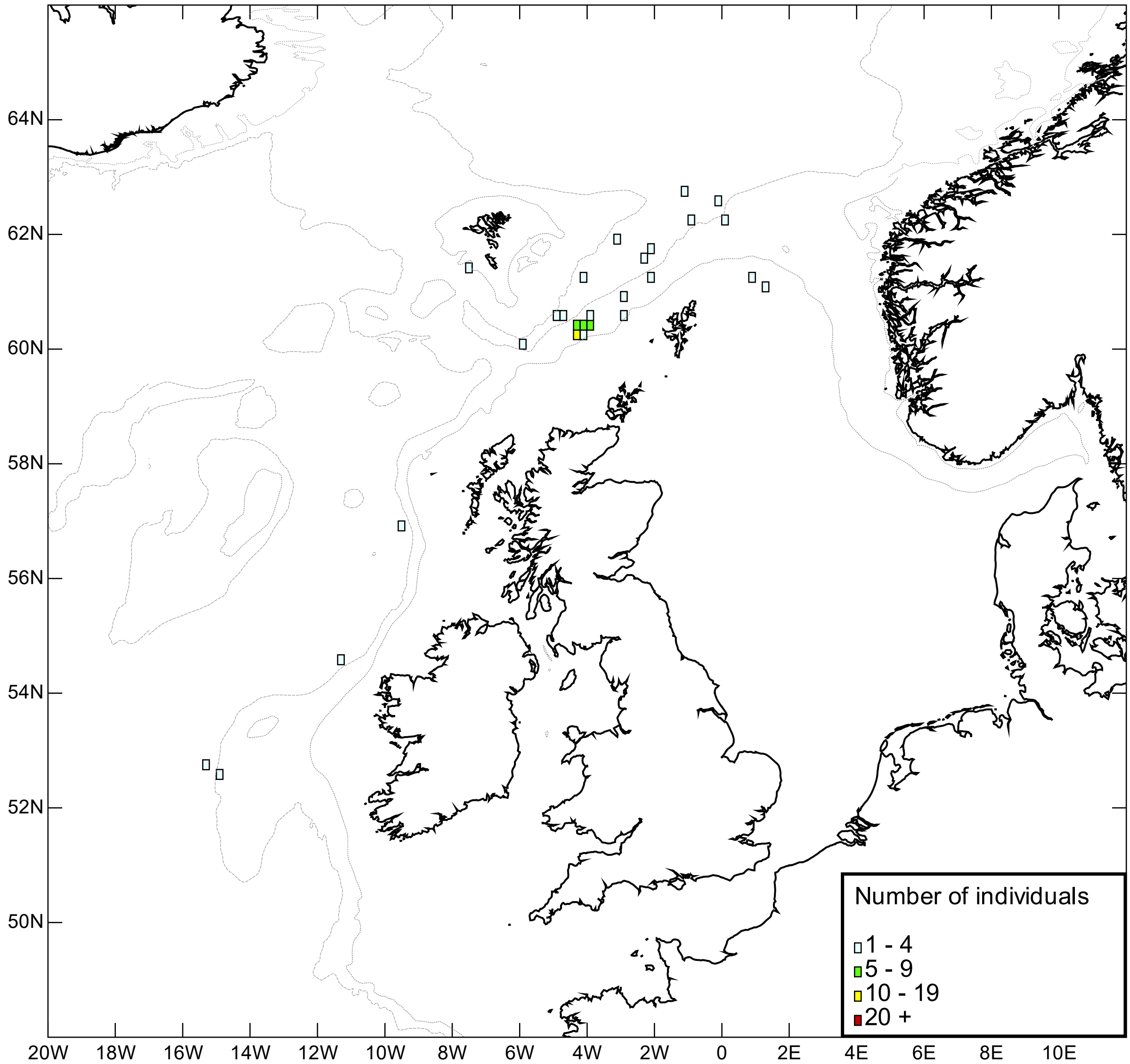

Figure 17. Sei whales encountered during geophysical surveys, 1995–2020.

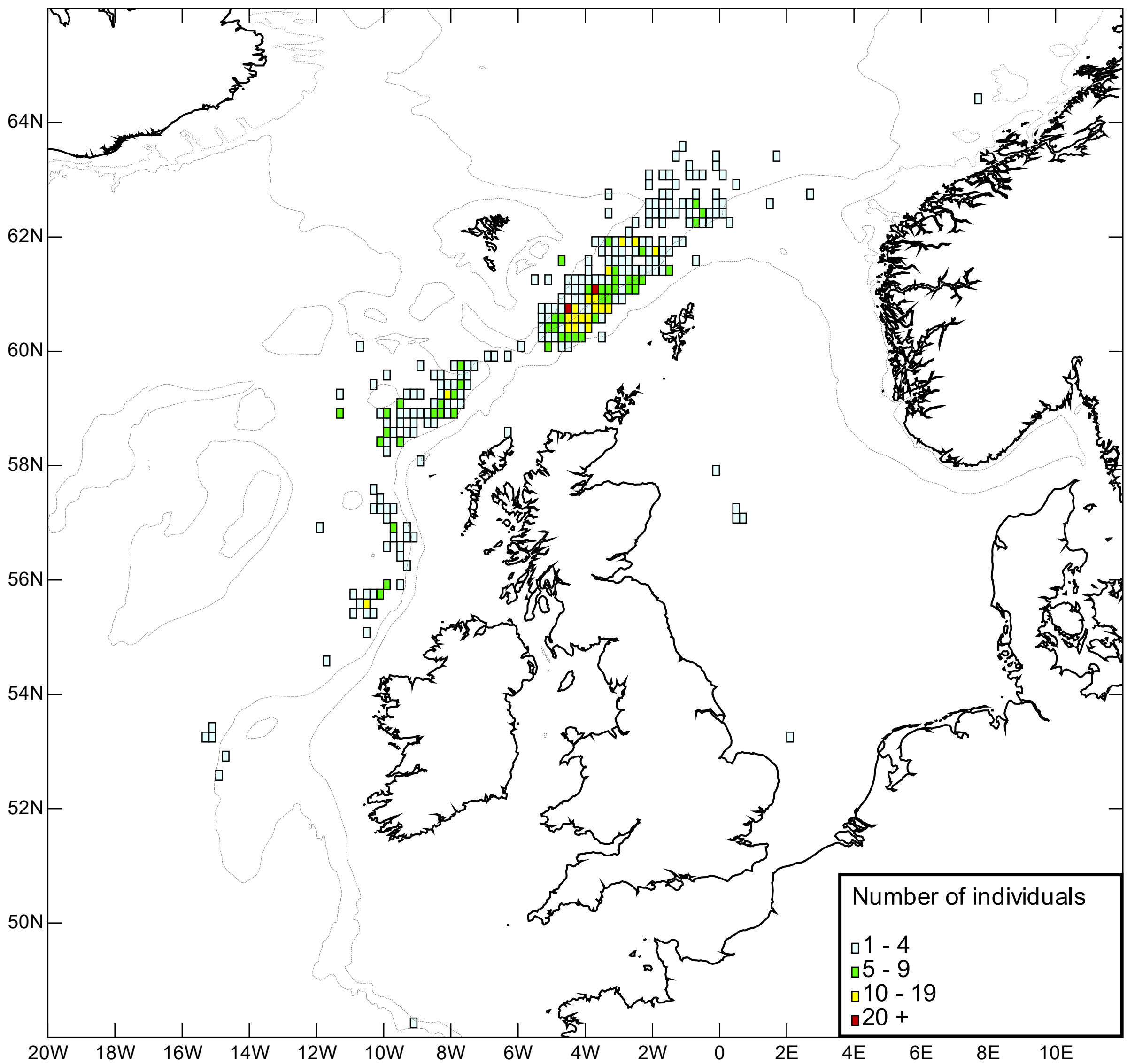

Figure 18. Sperm whales encountered during geophysical surveys, 1995–2020.

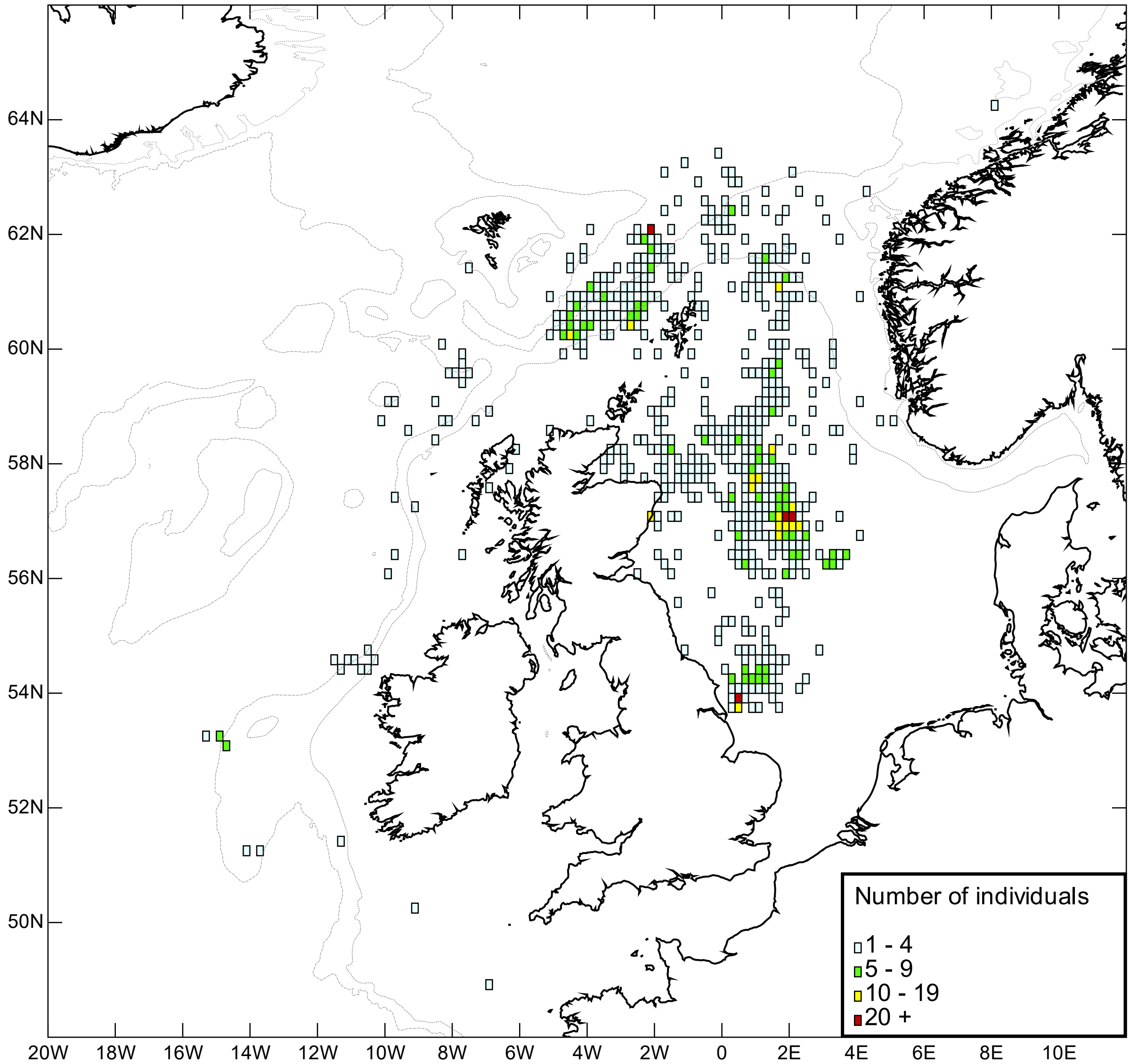

Figure 19. Minke whales encountered during geophysical surveys, 1995–2020.

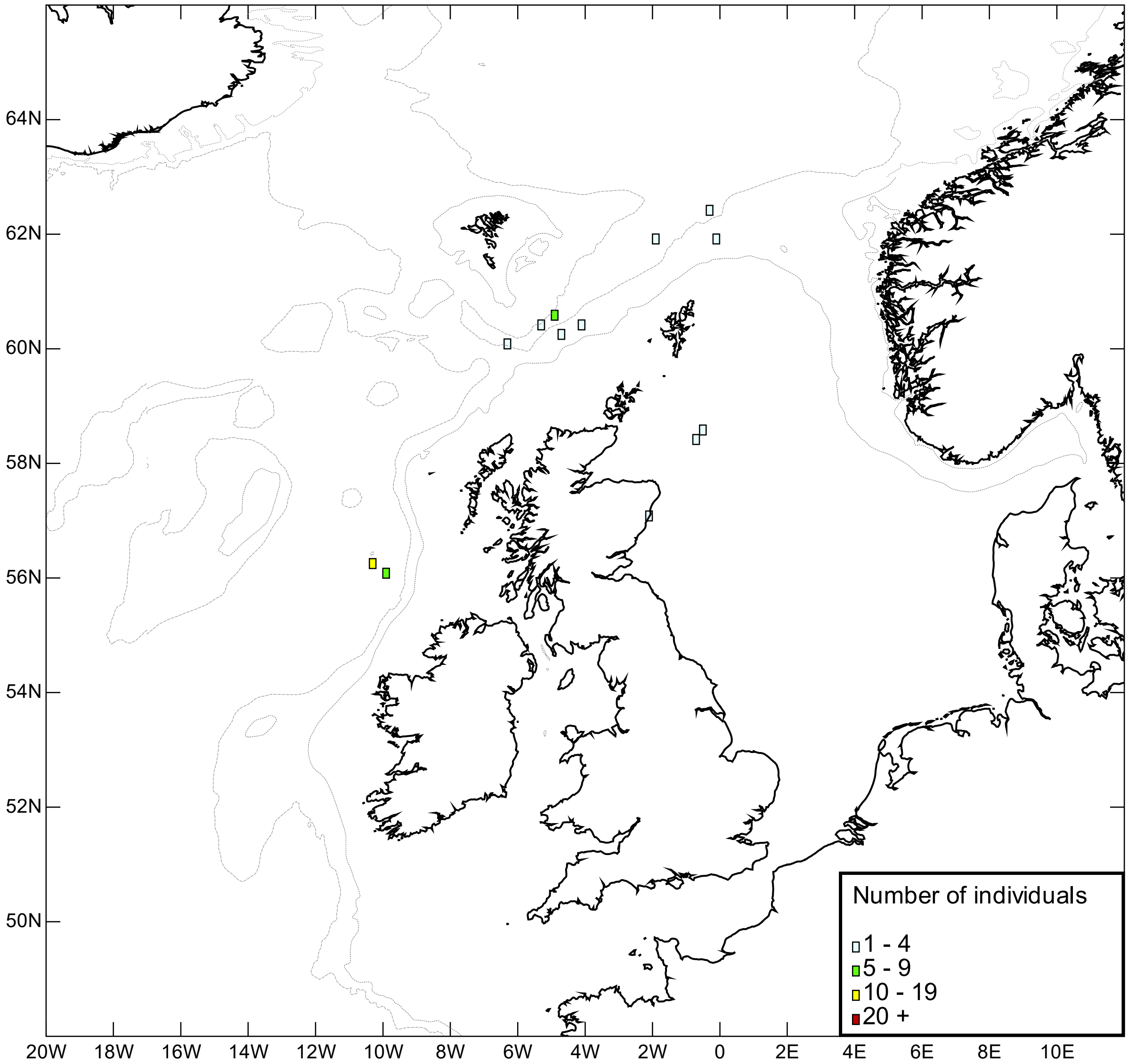

Figure 20. Northern bottlenose whales encountered during geophysical surveys, 1995–2020.

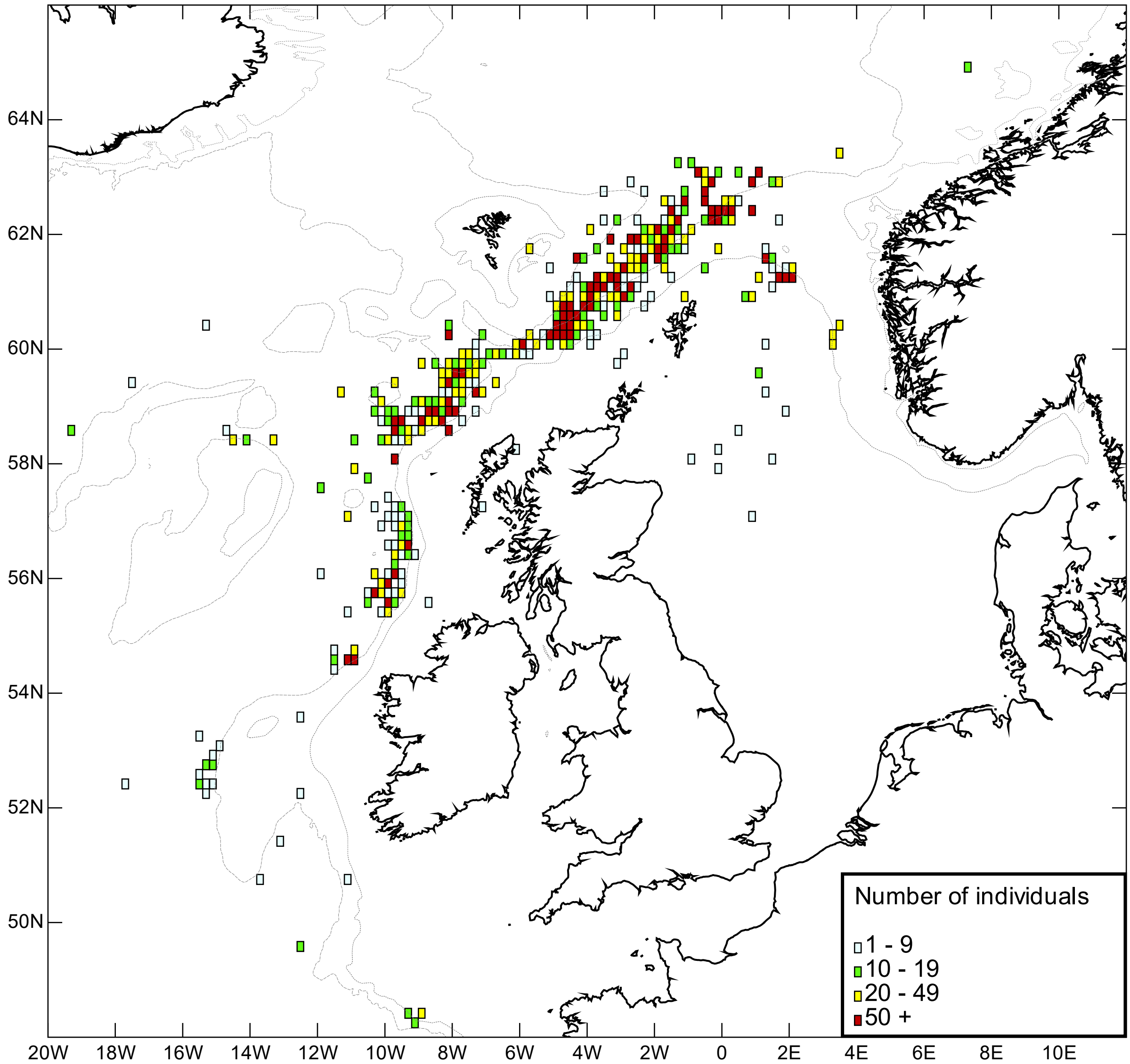

Figure 21. Long-finned pilot whales encountered during geophysical surveys, 1995–2020.

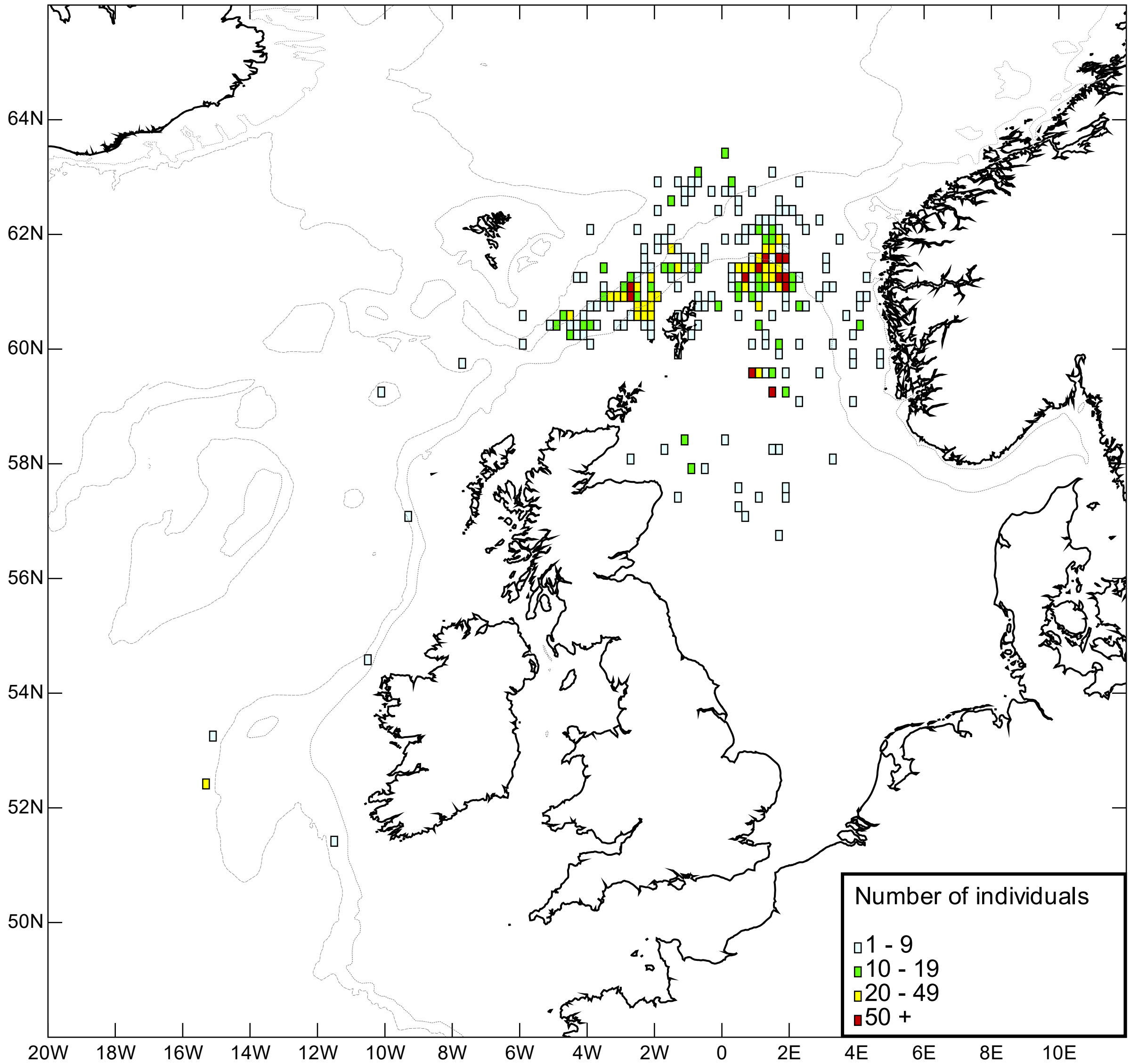

Figure 22. Killer whales encountered during geophysical surveys, 1995–2020.

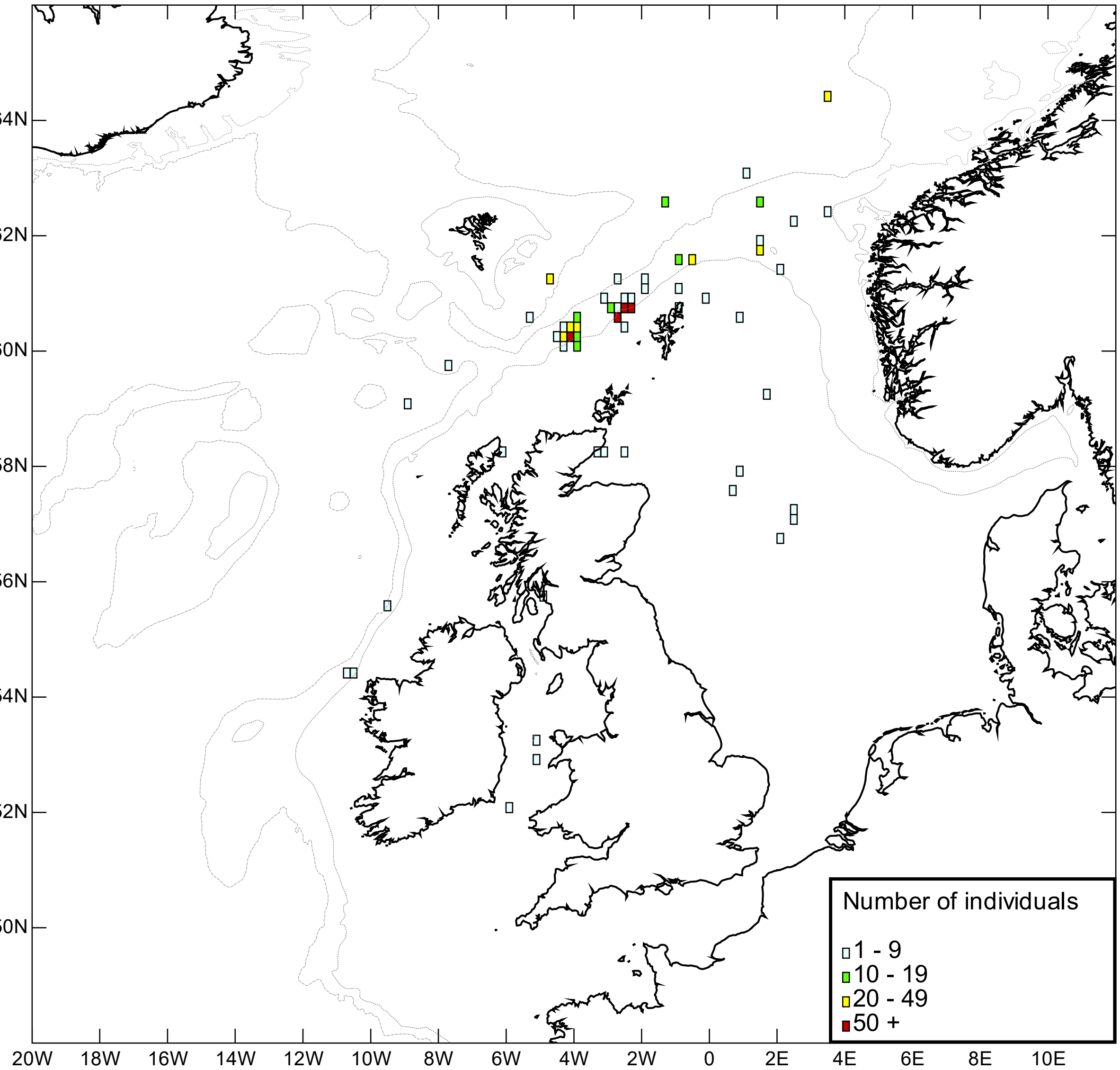

Figure 23. Risso's dolphins encountered during geophysical surveys, 1995–2020.

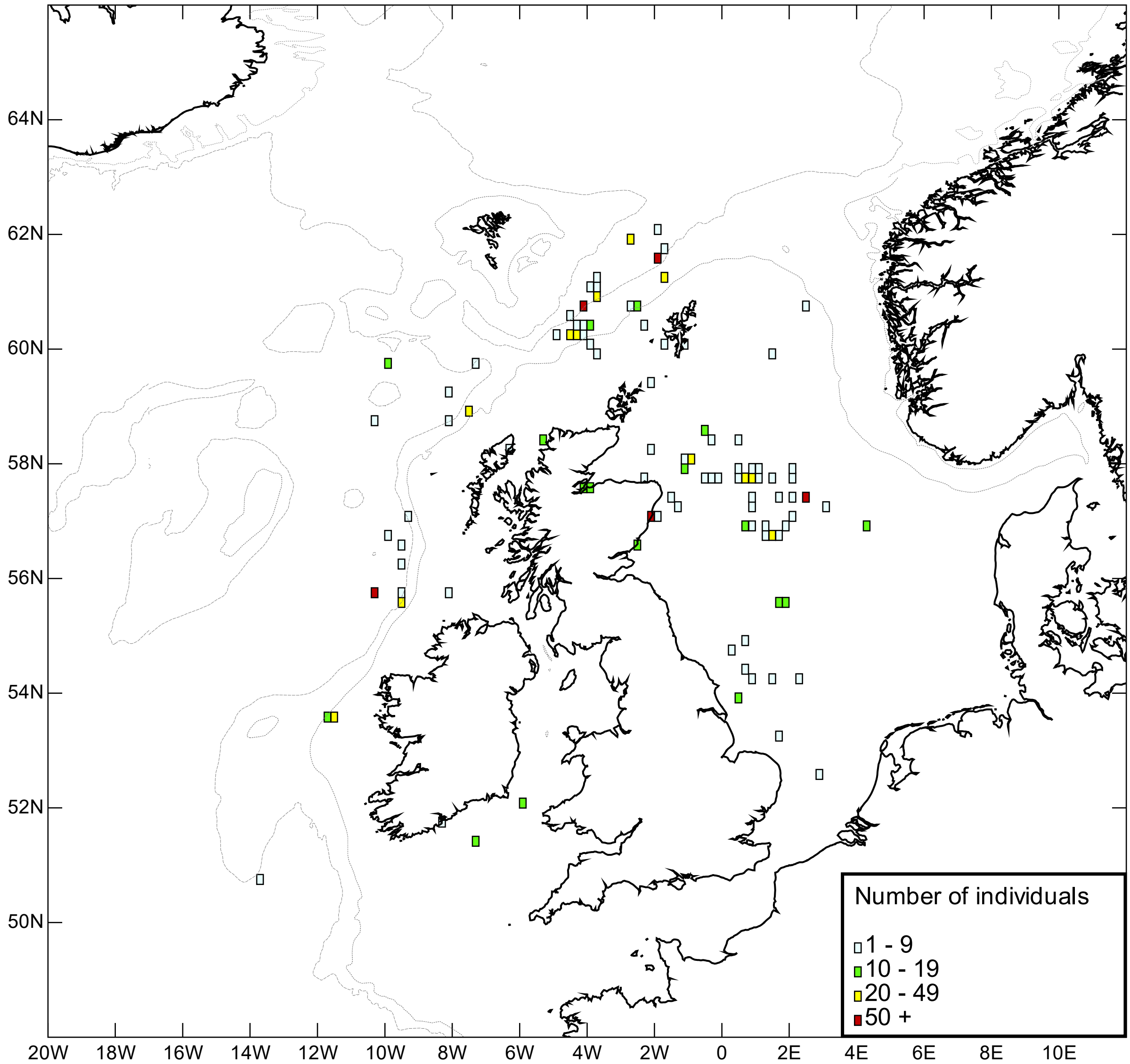

Figure 24. Bottlenose dolphins encountered during geophysical surveys, 1995–2020.

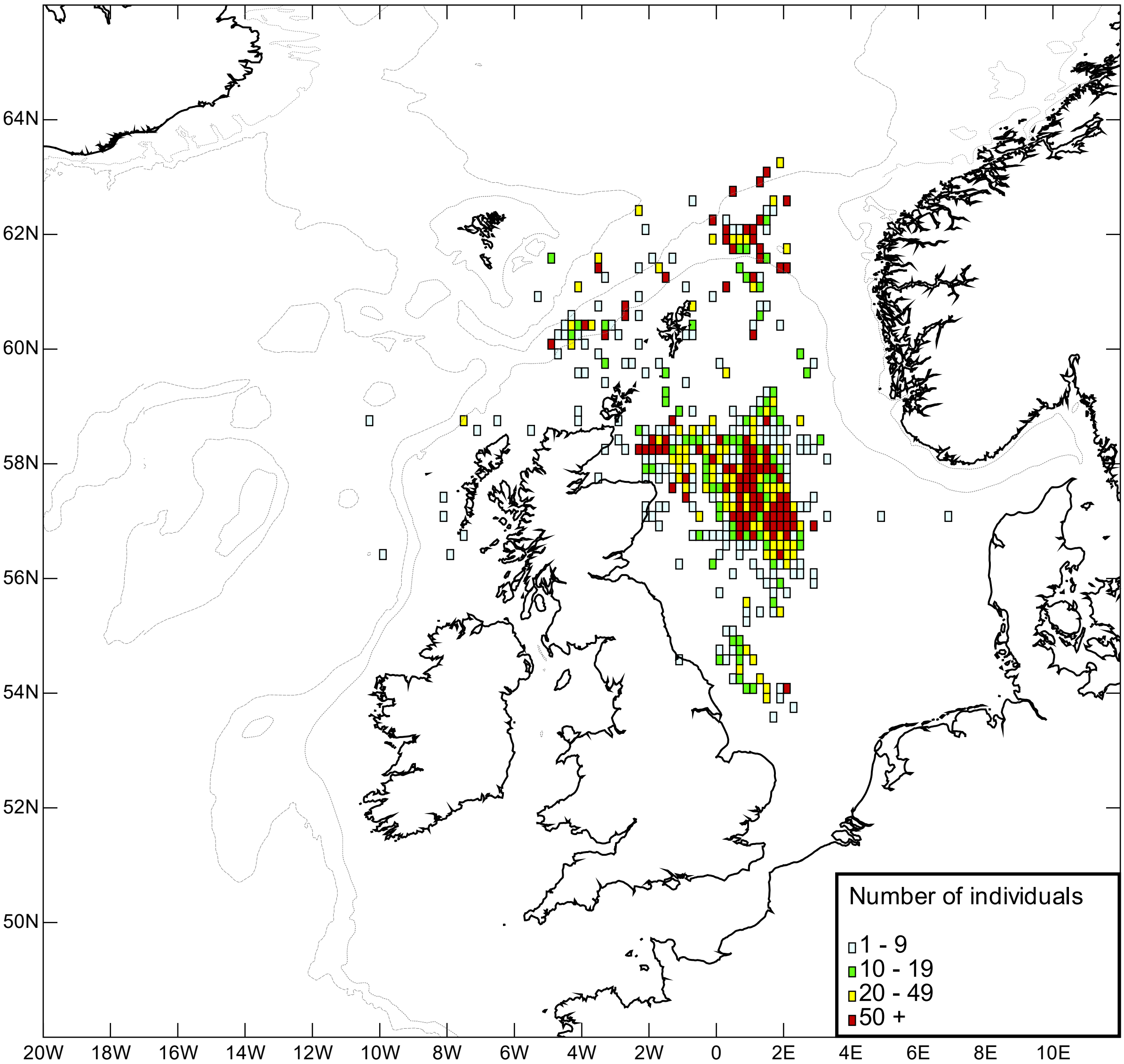

Figure 25. White-beaked dolphins encountered during geophysical surveys, 1995–2020.

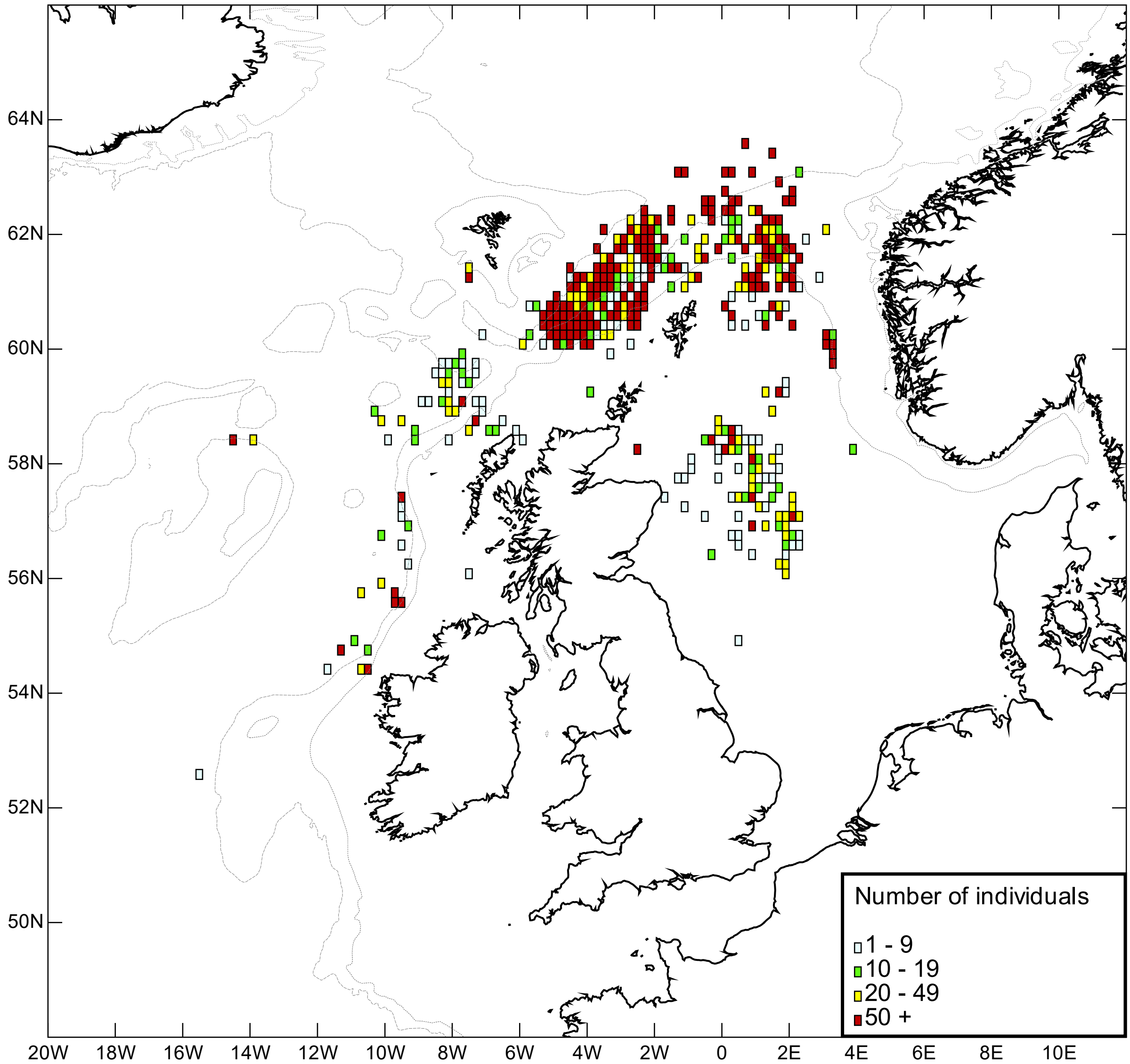

Figure 26. Atlantic white-sided dolphins encountered during geophysical surveys, 1995–2020.

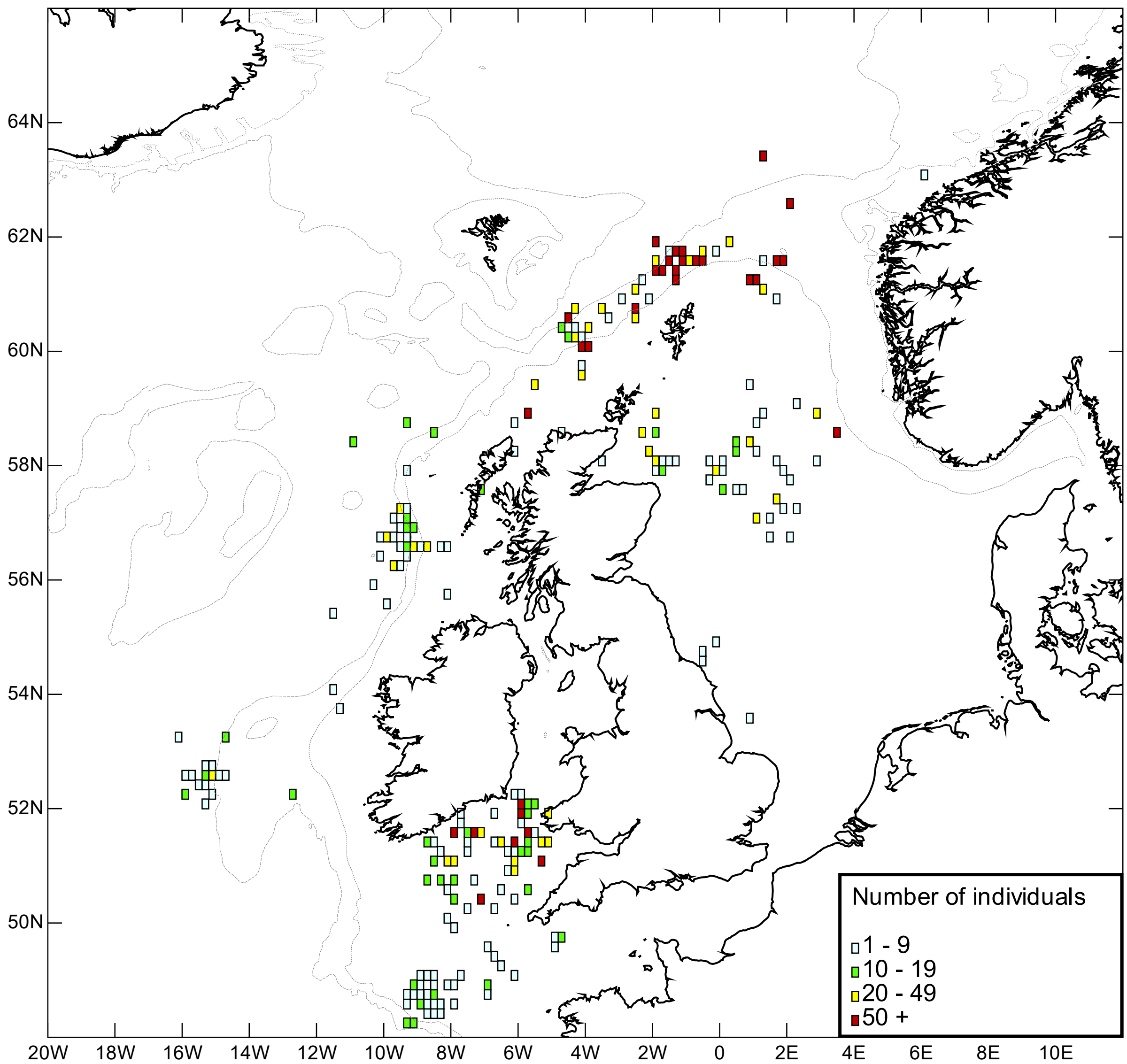

Figure 27. Common dolphins encountered during geophysical surveys, 1995–2020.

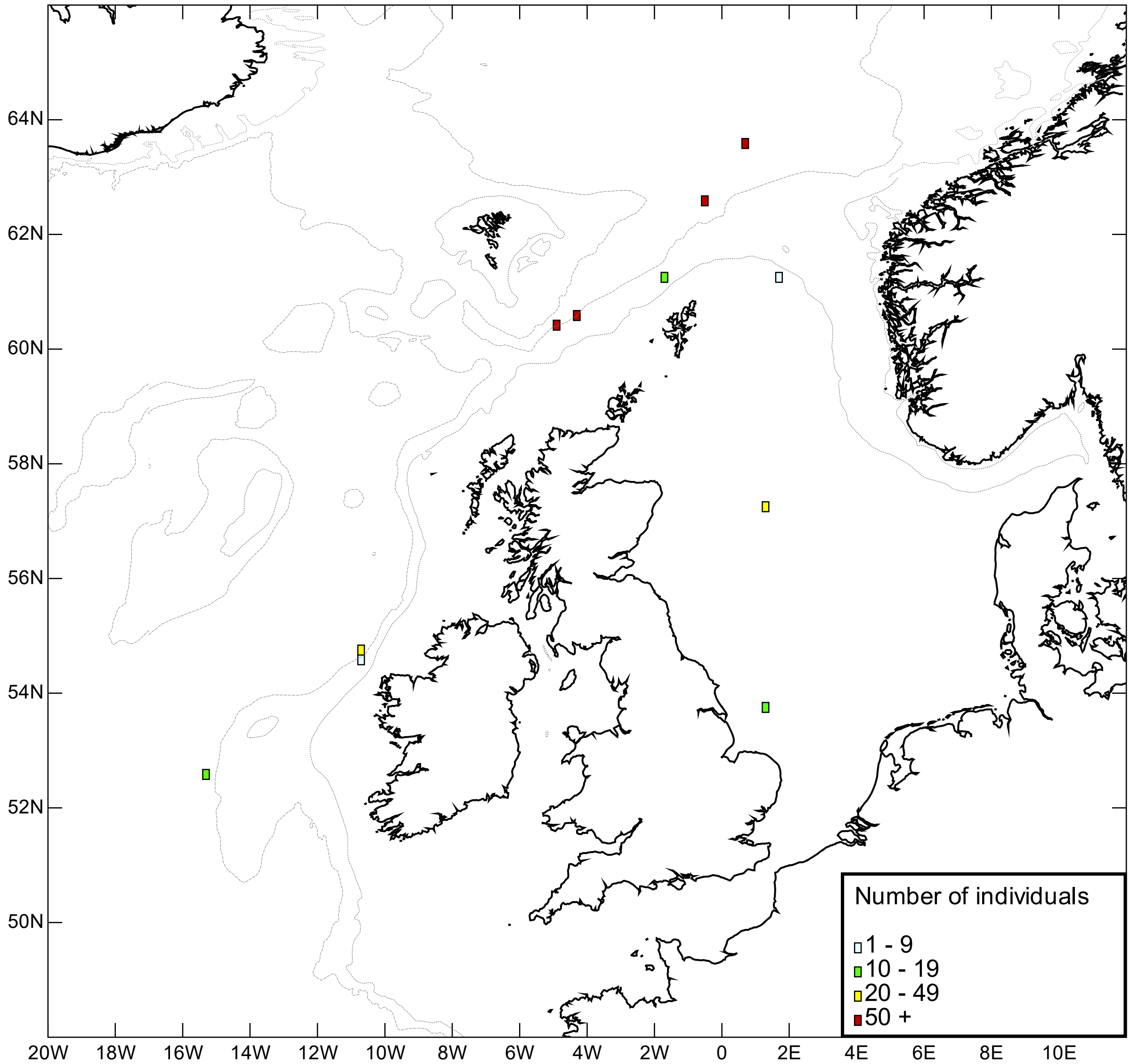

Figure 28. Striped dolphins encountered during geophysical surveys, 1995–2020.

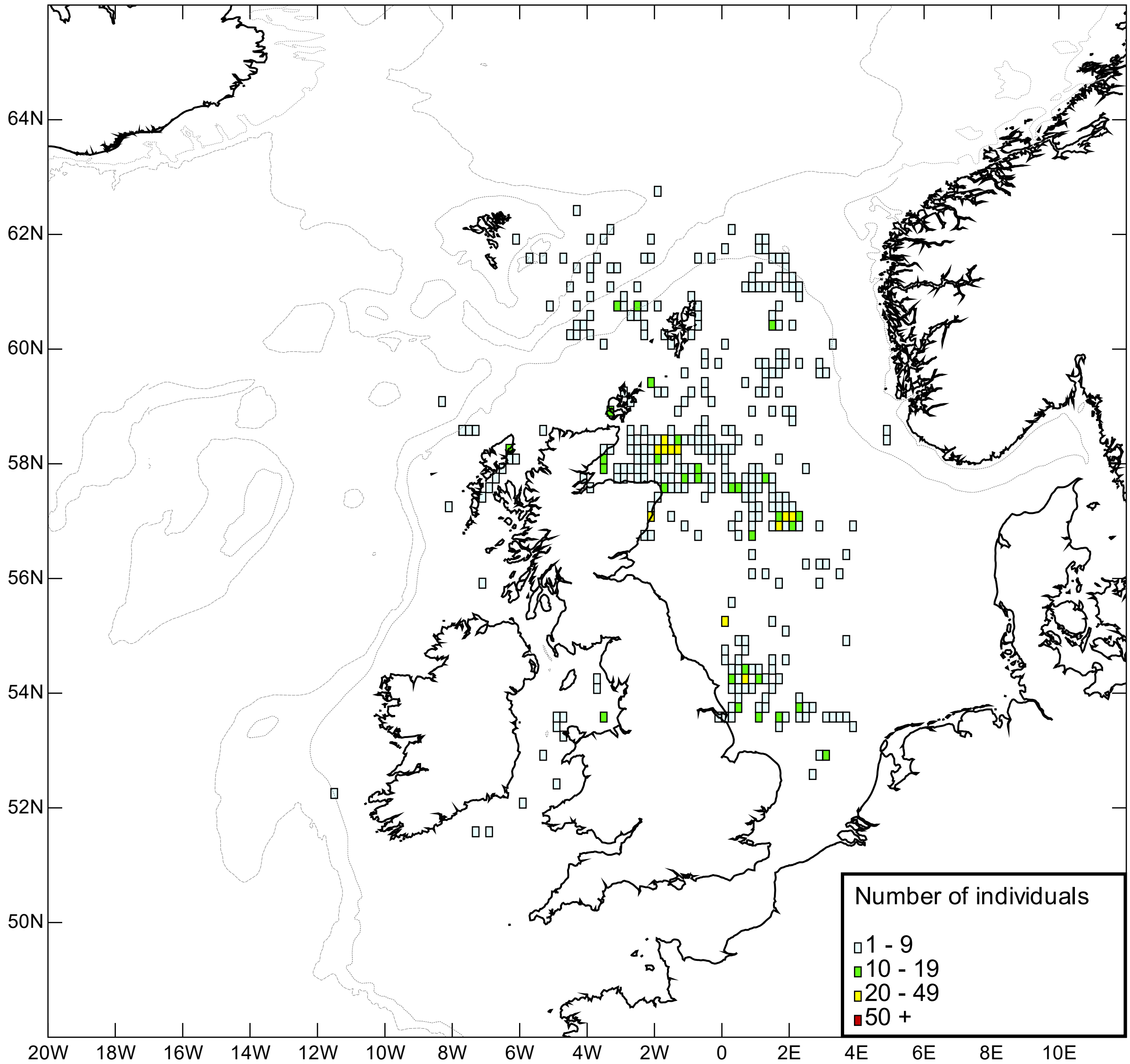

Figure 29. Harbour porpoises encountered during geophysical surveys, 1995–2020.

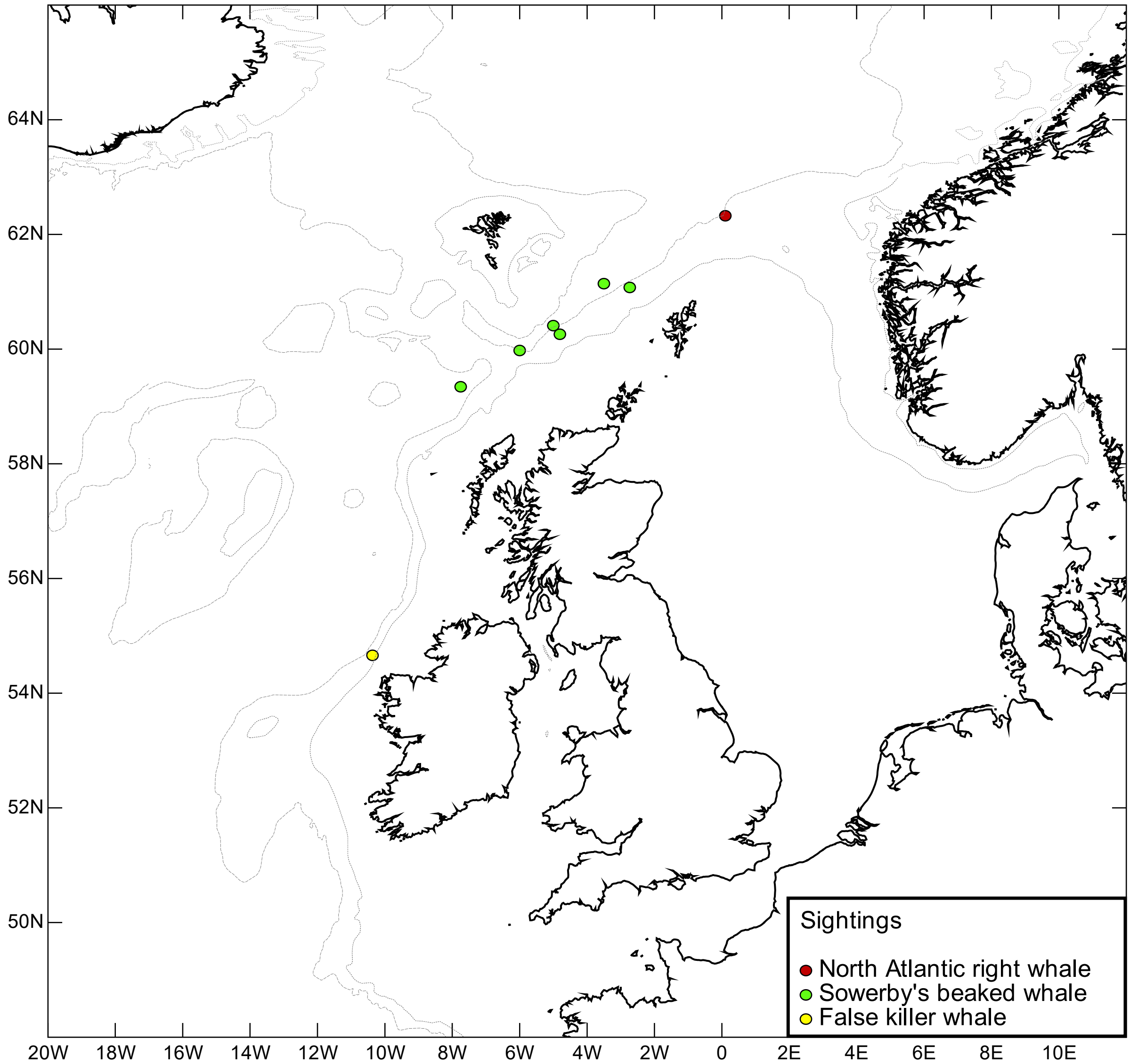

Figure 30. Sightings of marine mammal species encountered only occasionally during geophysical surveys, 1995–2020.

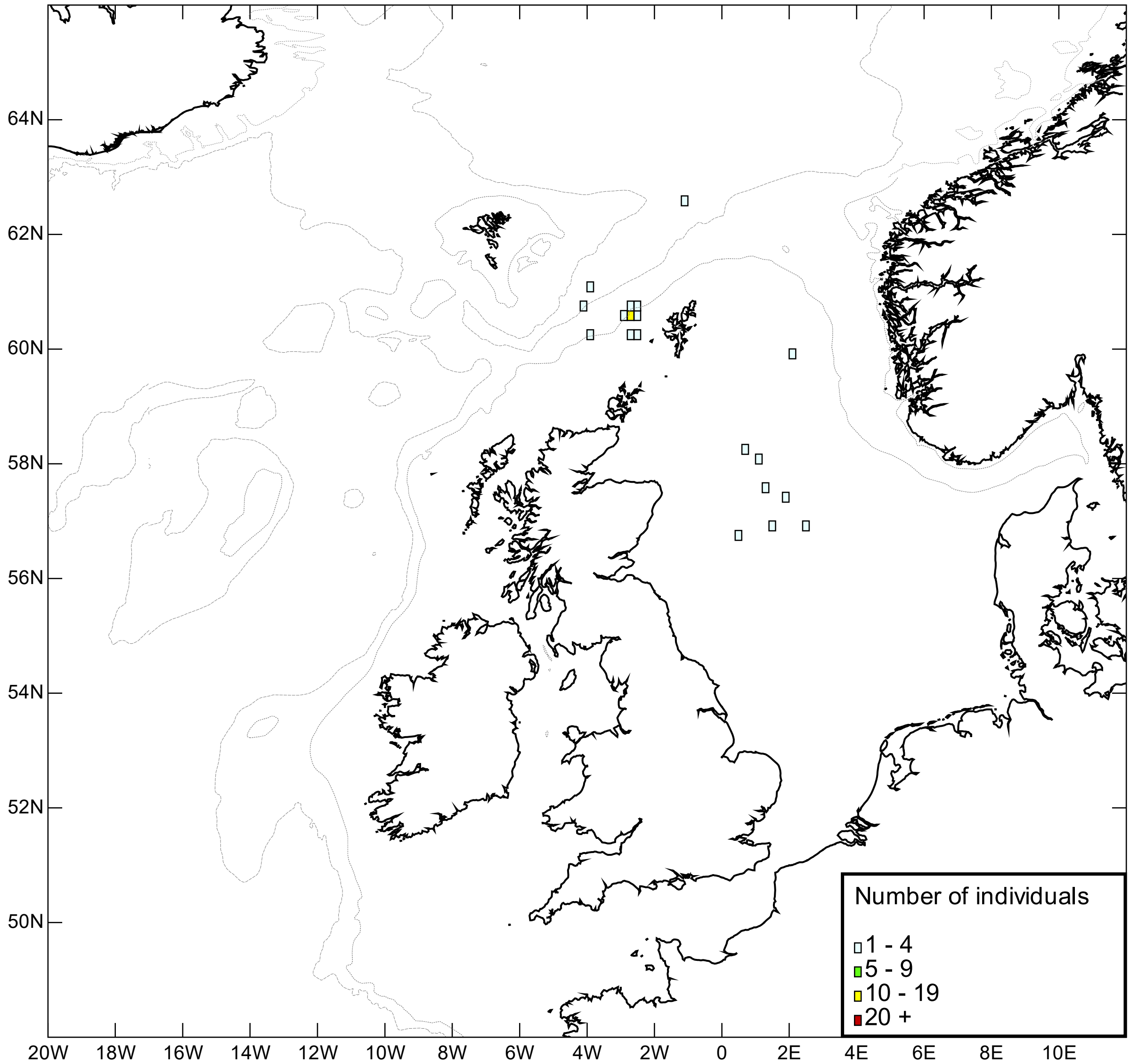

Figure 31. Basking sharks encountered during geophysical surveys, 1995–2020.

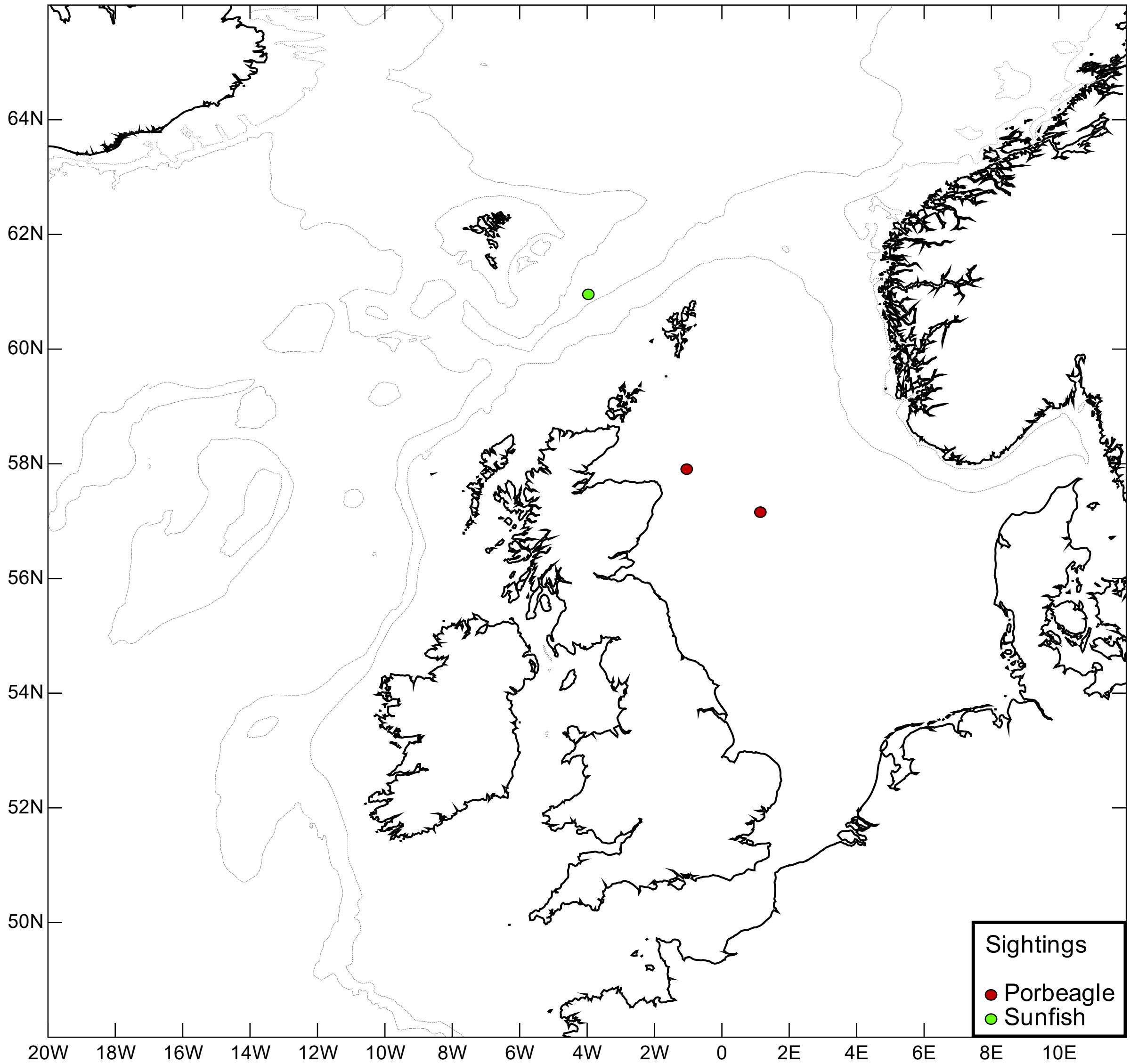

Figure 32. Sightings of porbeagles and sunfish encountered during geophysical surveys, 1995–2020.

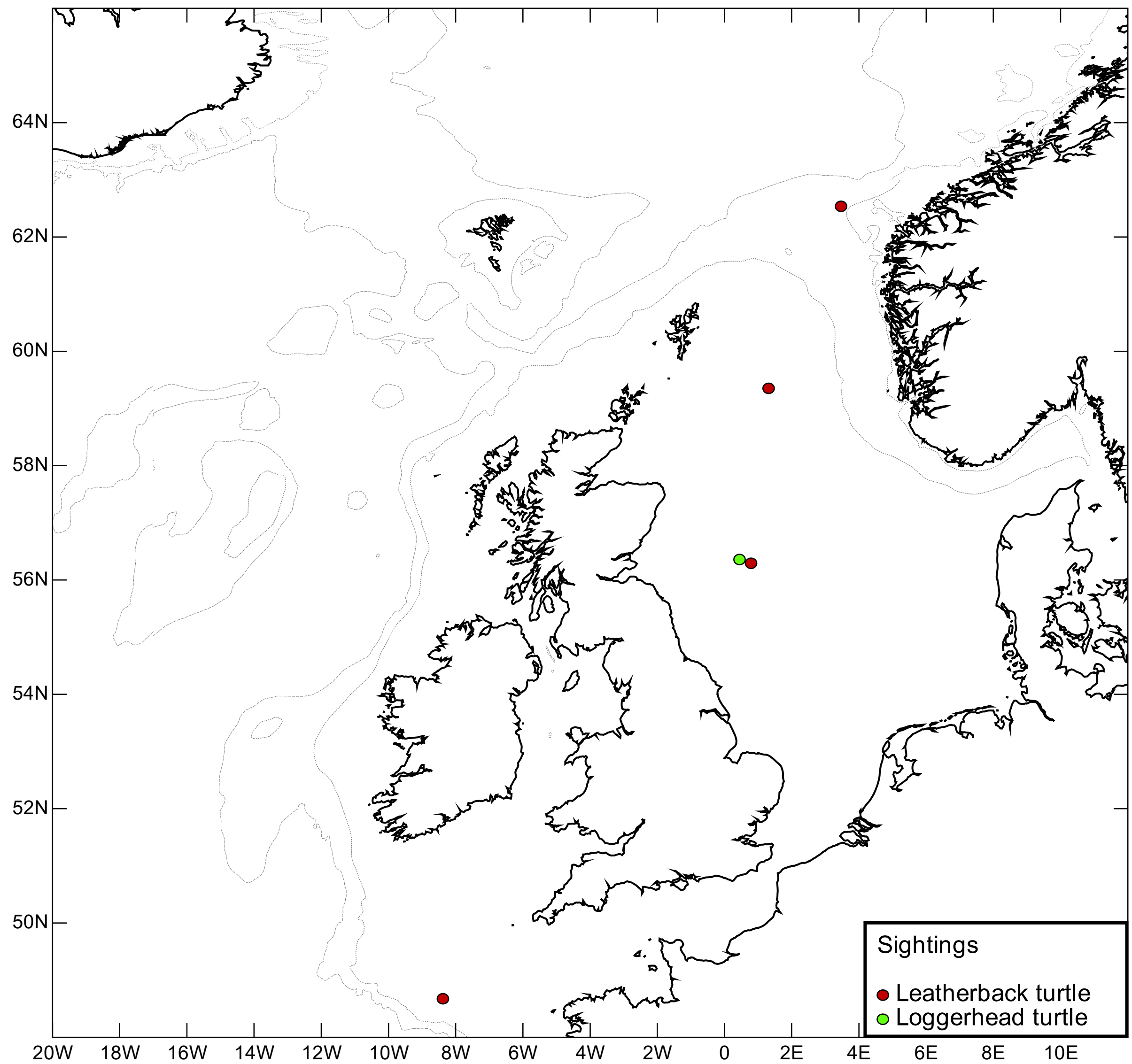

Figure 33. Sightings of turtles encountered during geophysical surveys, 1995–2020.

Appendix 2 - Scientific names of species mentioned in the text

Common name	Scientific name
Harbour seal	*Phoca vitulina*
Grey seal	*Halichoerus grypus*
Hooded seal	*Cystophora cristata*
Ringed seal	*Pusa hispida*
New Zealand fur seal	*Arctocephalus forsteri*
Bowhead whale	*Balaena mysticetus*
North Atlantic right whale	*Eubalaena glacialis*
North Atlantic right whale	*Eubalaena glacialis*
Humpback whale	*Megaptera novaeangliae*
Blue whale	*Balaenoptera musculus*
Fin whale	*Balaenoptera physalus*
Sei whale	*Balaenoptera borealis*
Minke whale	*Balaenoptera acutorostrata*
Sperm whale	*Physeter macrocephalus*
Northern bottlenose whale	*Hyperoodon ampullatus*
Sowerby's beaked whale	*Mesoplodon bidens*
Narwhal	*Monodon monoceros*
Short-finned pilot whale	*Globicephala macrorhynchus*
Long-finned pilot whale	*Globicephala melas*
Killer whale	*Orcinus orca*
False killer whale	*Pseudorca crassidens*
Melon-headed whale	*Peponocephala electra*
Pygmy killer whale	*Feresa attenuata*
Risso's dolphin	*Grampus griseus*
Bottlenose dolphin	*Tursiops truncatus*
White-beaked dolphin	*Lagenorhynchus albirostris*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Common dolphin	*Delphinus delphis*
Striped dolphin	*Stenella coeruleoalba*
Harbour porpoise	*Phocoena phocoena*
Basking shark	*Cetorhinus maximus*
Porbeagle	*Lamna nasus*

Common name	Scientific name
Sunfish	*Mola mola*
Loggerhead turtle	*Caretta caretta*
Leatherback turtle	*Dermochelys coriacea*

Appendix 3 - Glossary

2D survey: Two-dimensional exploration where a single streamer (containing hydrophones for detection of reflected sound) is used and the reflections from the subsurface are assumed to lie directly below the sail line that the survey vessel traverses. For regional surveys, sail lines are typically widely spaced (typically several kilometres apart) over a large area; a two-dimensional image is obtained and is generally used for wide-scale surveys.

3D survey: Three-dimensional exploration where multiple streamers (containing hydrophones for detection of reflected sound) are used, and sail lines are closely spaced (typically a few hundred metres apart). The use of multiple streamers results in the acquisition of many closely spaced sub-surface 2D lines, typically 25–50 m apart, and the data are processed into a three-dimensional image of the subsurface.

4D survey: 3D seismic survey repeated at an interval of months or years, to identify changes to the hydrocarbon reservoir over time due to production to maximise hydrocarbon recovery from the field.

Airgun: Device into which air is pumped into chambers at high pressure and then released through ports to form an oscillating bubble, thereby producing sound waves.

Boomer: An acoustic source used for high resolution shallow imaging, that uses electricity to cause two spring-loaded plates to repel each other rapidly, generating an acoustic pulse at frequencies of typically 300 Hz–5 kHz, penetrating 30–100 metres below the seabed. It is commonly towed on a sled and short towed hydrophone arrays receive the reflections of the sound.

Bottling: Behaviour where a seal assumes a vertical position with its head out of the water, allowing it to breathe while resting or sleeping.

Breaching: Behaviour where a cetacean launches itself into the air head-first and falls back into the water with a splash.

Cetacean: The group of marine mammals comprising the whales, dolphins and porpoises.

Chirp: These sub-bottom profilers transmit a pulse consisting of a continuous sweep of frequencies ranging from 1–40 kHz. A chirp is often hull-mounted.

Dedicated MMO: Person dedicated to the role of MMO and not any other job on board.

Delphinid: Cetaceans of the family Delphinidae, a subdivision of the odontocetes which in north-west European waters includes the dolphins, long-finned pilot whales and killer whales.

Effort: Number of hours of visual or acoustic monitoring.

Full power: Operating the acoustic source (e.g. airguns or a sub-bottom profiler) at its full operational level, reached at the end of a soft start.

Impulsive (or pulsed) sounds: Impulsive sounds are typically brief, have a rapid rise time and cover a wide frequency range. Examples include sounds from seismic airguns, impact piling, sonar, etc. Pulses may be single (e.g. single firing of an airgun) or multiple (e.g. repeated airgun firing or repeated pile strikes).

JNCC: Joint Nature Conservation Committee; the public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation.

Line change: The activity of turning the vessel at the end of one survey line prior to commencement of the next line.

Logging: Behaviour where cetaceans float motionless at the water surface.

Lunge-feeding (or lunging): A method of feeding used by some baleen whales where they lunge forwards with mouths open engulfing a large volume of water and any prey species contained therein are sieved from the water using the baleen plates.

Marine European Protected Species: Marine species in Annex IV(a) of the EC Habitats Directive that occur naturally in the waters of the United Kingdom; these consist of several species of cetaceans (whales, dolphins, and porpoises), turtles and the Atlantic sturgeon.

Marine Protected Areas (MPAs): Marine areas designated and managed for nature conservation, including Special Areas of Conservation (SACs), Marine Conservation Zones (MCZs) and, in Scotland, Nature Conservation Marine Protected Areas (NCMPAs).

Marine vibroseis: An alternative source that produces controlled acoustic signals by displacement of water using a vibrating plate or shell.

Milling: Behaviour where cetaceans continue to surface in the same general vicinity.

Mini airgun: Airgun of small volume (currently defined as less than or equal to 10 cu.in.).

Mitigation zone: The area where an MMO or PAM operator keeps watch for marine mammals (and delays the start of activity should any marine mammals be detected); currently the area within 500 m of the centre of the airgun array or other acoustic source.

MMO: Marine Mammal Observer; person who will monitor for the presence of marine mammals visually and will provide advice to enable compliance with the JNCC guidelines.

Multibeam echo sounder: An echo sounder producing a fan of acoustic beams to provide sounding information on each side of the vessel's track, covering an area from twice the water depth up to 10 times the water depth for high performance systems. The width of the swathe depends on the number of sound beams, the operating frequency, and the water depth. High frequencies (e.g. 200 kHz or 400 kHz) are used in shallower waters, whereas lower frequencies (e.g. 12 kHz) are used in deeper waters.

Mysticete: Cetaceans belonging to the suborder Mysticeti, also known as baleen whales. Mysticetes lack teeth but have baleen plates; they have two external blowholes. Mysticetes in north-west European waters include the blue whale, fin whale, sei whale, humpback whale and minke whale.

Non-dedicated MMO: Person undertaking the role of MMO who may also do another job on board.

Non-parametric statistical test: A statistical test that is appropriate where the underlying data are not normally distributed.

OBS survey: Ocean Bottom Seismic survey, including both OBC (Ocean Bottom Cable) and OBN (Ocean Bottom Node) surveys. Streamers / cables or nodes (containing both hydrophones and geophones) are laid on the seabed and a separate source vessel is utilised.

Odontocete: The suborder of cetaceans including the toothed whales and dolphins, which possess teeth and have a single external blowhole; odontocetes in north-west European waters include the sperm whale, beaked whales, killer whale, long-finned pilot whale, dolphins and harbour porpoise.

PAM: Passive Acoustic Monitoring; listening for marine mammal vocalisations using hydrophones deployed in the water linked to specialist software.

PAM operator: Person who operates PAM equipment to monitor for the presence of marine mammals acoustically and will provide advice to enable compliance with the JNCC guidelines.

Permanent Threshold Shift (PTS): A permanent shift in the auditory threshold. It may occur suddenly or develop gradually over time. A permanent threshold shift results in permanent hearing loss.

Pinger: An acoustic source, often hull-mounted, producing 'pings' at a range of single frequencies typically 3.5–7 kHz, penetrating from a few metres below the seabed to more than 50 m.

Pinniped: The group of marine mammals comprising the seals, fur seals, sea lions and the walrus.

Porpoising: Swimming behaviour where cetaceans leap clear of the water whilst moving forwards.

Pre-shooting search: Search for marine mammals prior to commencing firing of the airguns or other acoustic source.

Rorqual whale: Baleen whale of the family Balaenopteridae, all possessing many longitudinal throat grooves that allow expansion of the mouth cavity when feeding.

Seismic survey: Survey where low frequency sound waves are generated (by using airguns) and sent into the seabed and the reflected energy is recorded (with hydrophones) and processed to produce images of the geological strata below the seabed.

Side-scan sonar: A side-scan sonar transmits a pulse in a narrow beam directly under the source and to the side to an approximate distance of 50–200 m. The pulse does not penetrate the seabed but is reflected off it to build up an image of objects on the seabed. Side-scan sonars operate at high frequencies (e.g. 120 kHz or 410 kHz).

Single beam echo sounder: An echo sounder produces a high frequency pulse, typically 10 kHz to 200 kHz (lower frequencies being used for greater depths and higher frequencies in shallower water). Water depth is determined by measuring the two-way travel time of the pulse. A single beam echo sounder operates vertically below the survey vessel to gather a single line of sounding.

Site survey: Survey over a specific site to identify seabed and shallow subsurface hazards (e.g. shallow pockets of gas) prior to the location of infrastructure or a drilling rig. The technique is that of a 2D survey but typically utilises smaller volumes of airguns, commonly around 160 cu.in. Other equipment may also be used, including side-scan sonar and sub-bottom profilers such as boomers, pingers, sparkers and chirp systems.

Soft start (or ramp up): Process whereby the power of an airgun array (or other acoustic source) is built up slowly from a low energy start-up, gradually and systematically increasing the output until full power is achieved.

Sound exposure level (SEL): a measure of the pulse energy and is the integral of the squared sound pressure over a stated time interval (e.g. 1 second). The units used for SEL are dB re 1 μPa^2-s.

Sound pressure level (SPL): a measure of the sound pressure. It is measured relative to a reference value; in water this reference value is 1 μPa (it is normally 20 μPa for airborne sound). The units used for SPL in water are therefore dB re 1 μPa.

Source: The source of the noise (e.g. for a seismic survey the airguns).

Source level: The pressure level that would be measured at some standard distance (usually 1 m) from an ideal point source radiating the same amount of sound as the actual source. The unit is dB re 1 μPa @ 1 m. In practice, source levels are rarely measured at the reference distance, but instead are measured at some distance and the estimated source level calculated by modelling taking account of propagation loss from 1 m to the actual measurement distance.

Sparker: An acoustic source used for high resolution shallow imaging, that uses electricity to vaporise water creating a collapsing bubble generating pulsed sound typically at frequencies of 50 Hz–4 kHz, penetrating to a few hundred metres below the seabed. Short, towed hydrophone arrays receive the reflections of the sound.

Spy-hopping: Behaviour where a cetacean will position itself vertically with its head poking above the water surface.

Sub-bottom profiler: A system comprising an acoustic source and receiver used for determining stratification of sediments to shallow sub-surface depths of around 50 m to a few hundred metres below the seabed. Systems (e.g. pingers, boomers, sparkers, chirp systems) utilise different frequencies, with higher frequencies achieving less penetration but higher resolution.

Tail-slapping: Behaviour where a cetacean forcefully slaps its tail flukes on the water surface.

Temporary Threshold Shift (TTS): A temporary shift in the auditory threshold. It may occur suddenly after exposure to high levels of noise and results in temporary hearing loss.

UKCS: UK continental shelf.

Vertical Seismic Profiling (VSP): undertaken during drilling operations where the geophone is lowered into the borehole and the airguns are lowered over the side of the drilling rig (zero offset VSP) or from a vessel at a fixed location (offset VSP) or from a vessel traversing lines away from the platform (walkaway VSP).