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Marine mammal observations during seismic surveys from 1994-2010

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Peer review was undertaken throughout this project both internally by JNCC and externally by Department of Energy and Climate Change (DECC).

Summary

Data from 1,196 seismic surveys in UK and adjacent waters between 1994 and 2010 were examined to assess the effects of seismic operations on marine mammals and overall trends in compliance with the JNCC Guidelines for Minimising the Risk of Injury and Disturbance to Marine Mammals from Seismic Surveys (JNCC 2010 and earlier versions). Over 190,000 hours were recorded as monitoring for marine mammals (over 181,000 hours visual monitoring and over 9,000 hours acoustic monitoring), with airguns firing for 38.8% of this time.

There were 9,073 sightings or acoustic detections of marine mammals, comprising 124,024 individuals. The most frequently encountered species (where identified) was the white-beaked dolphin, although due to larger pod sizes Atlantic white-sided dolphins were the most numerous in terms of total number of individuals. Minke whales, sperm whales, harbour porpoises and long-finned pilot whales were also encountered frequently, with fin whales, killer whales and short-beaked common dolphins seen moderately often. Changes in occurrence of fin whales and harbour porpoises in 2006-2010 compared to 1994-2005 were not adequately explained by survey effort.

When ‘large arrays’ of airguns (500 cubic inches [cu. in.] or more) were firing a significant response (lateral displacement, more localised avoidance or a change in behaviour) was evident for all small and medium-sized odontocetes (including beaked whales) where sample sizes permitted testing, with the exception of Risso’s dolphin. The minke whale and the fin whale were the only individual species of baleen whale where a significant response to ‘large arrays’ was found. Lateral displacement, where found, sometimes extended beyond the visual range of the observer. Behavioural responses observed when ‘large arrays’ were firing included changes in swimming or surfacing behaviour and there were indications that cetaceans remained near the water surface at these times. Cetaceans were recorded as feeding significantly less often when ‘large arrays’ were active. In addition to the responses found in cetaceans, grey seals were also displaced when ‘large arrays’ were firing.

When ‘small arrays’ (less than 500 cu. in.) were firing, fewer effects on marine mammals were noted. However, significant lateral displacement was found for sperm whales and harbour porpoises when ‘small arrays’ were firing and localised avoidance was apparent for some species groups. Furthermore, there were indications that initial tolerance of ‘small arrays’ by delphinids and small odontocetes might have decreased as surveys progressed. While with ‘large arrays’ cetaceans sometimes remained near the surface when the airguns were firing, with ‘small arrays’ there were indications that cetaceans may remain submerged more during periods of firing. Other effects on swimming or surfacing behaviour were not evident with ‘small arrays’.

There was some evidence that the soft start may be an effective mitigation measure. Detection rates of cetaceans during the soft start were significantly lower than when the airguns were not firing and on surveys with ‘large arrays’ more cetaceans were observed avoiding or travelling away from the survey vessel during the soft start than at any other time. These results were found for all of the few species or species groups that were able to be tested. Further studies on the effectiveness of the soft start, particularly for other species, would be valuable.

Long term trends in compliance with the JNCC guidelines were examined. Standards of pre-shooting searches have remained stable over the years, while standards of soft starts and the implementation of delays in firing when required have improved. However, although there has been improvement, of particular concern was the number of occasions when

delays in firing were not properly implemented following a detection of marine mammals in the mitigation zone as compliance with this aspect of the guidelines still lags behind that of pre-shooting searches and soft starts. Incorrect procedures in a delay situation were sometimes due to the subsequent soft start being too short, but more often due to the delay not being long enough.

This report represents one of the longest term analyses of MMO data to date and provides a valuable resource for investigating the potential impacts of industrial activities on marine mammals and the effectiveness of the guidelines and compliance therewith. Continued collection and analysis of MMO data will continue to improve mutual understanding of these issues and benefit both the conservation of these species and appropriate mitigation measures.

Contents

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 25-50m 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 in order 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.

Baleen whale Cetaceans belonging to the suborder Mysticeti, which lack teeth and have two external blowholes; baleen whales in north-west European waters include the blue whale, fin whale, sei whale, humpback whale and minke whale.

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.

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 Firing the airguns at their full operational level, reached at the end of a soft start.

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.

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 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.

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

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 500m of the centre of the airgun array.

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.

Mysticete The suborder of cetaceans including the baleen whales, which lack teeth and 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.

OBC survey Ocean Bottom Cable survey, where the streamers or cables (containing both hydrophones and geophones) are laid on the sea bed 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.

Pinniped The group of marine mammals comprising the 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.

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 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.

Site survey Survey over a specific site in order 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 and sparkers.

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

Source The source of the noise, i.e. for a seismic survey the airguns.

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

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

Time-sharing When vessels engaged on adjacent surveys take turns to run survey lines to avoid interference from the noise of each other's airguns. This is becoming less necessary with improvements in software and increases in computer processing power.

UKCS UK continental shelf.

VSP Vertical seismic profiling; 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).

1 Introduction

Over the past few decades concern has developed over potential negative impacts of anthropogenic noise on marine mammals. Amongst the activities of concern are marine seismic surveys, used to explore the sea floor in the search for oil and gas reserves. This exploration is achieved by directing sound, produced by airguns, at the seabed and analysing the resultant reflections of that sound to map the geological structures below the sea floor. The airguns produce high levels of impulsive low frequency sound with an inherent risk of disturbance and possibly acoustic trauma (e.g. auditory injury) to marine mammals.

In 1992, the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS; now the Agreement on the Conservation of Small Cetaceans of the Baltic, North east Atlantic, Irish and North Seas) introduced a requirement to work towards the prevention of significant disturbance, especially of an acoustic nature, to small cetaceans. In 1995, the UK government adopted a set of guidelines developed by the Joint Nature Conservation Committee (JNCC) to minimise disturbance to small cetaceans from seismic surveys in particular, partly as a response to the ASCOBANS requirement. Amongst the provisions of these guidelines was the requirement to monitor for the presence of cetaceans prior to commencing firing the airguns; this was the origin of the role of the marine mammal observer (MMO) on seismic surveys. The guidelines have been revised on a number of occasions and since 1998 have included all marine mammals. The relevant regulator is the Department of Energy and Climate Change (DECC) and the latest revision of the guidelines, the JNCC Guidelines for Minimising the Risk of Injury and Disturbance to Marine Mammals from Seismic Surveys, was published in August 2010 (JNCC 2010). The guidelines also aim to reduce the risk of causing deliberate injury or deliberate disturbance to European Protected Species (EPS, including cetaceans) as required by Article 12 of the EC Habitats Directive (92/43/EEC) and the Directive's transposition into UK legislation. All applications to conduct seismic surveys for oil and gas exploration within the UKCS require consent from DECC. JNCC are consulted on all such applications, as one of DECC's statutory consultees, with the JNCC guidelines informing the consent conditions for such surveys.

Monitoring for the presence of marine mammals prior to commencing firing of the airguns is a key component of the JNCC guidelines. This is primarily achieved by visual means (i.e. MMOs), however there is provision for passive acoustic monitoring (PAM) to be used at times when conditions are not conducive to effective visual monitoring (e.g. darkness, poor visibility and increased sea states). If marine mammals are detected within a defined mitigation zone, then the start of airgun firing must be delayed. When it is clear to start, the level of firing must increase gradually by using a soft start/ ramp up procedure. The primary role of the MMO is to provide advice to enable the crew to comply with the guidelines and hence mitigate potential negative impacts of seismic operations on marine mammals. This work involves collecting data on the seismic operations, the watches and any marine mammals observed. Marine mammal recording forms are available for this purpose (JNCC 2012a) and all data from seismic surveys in UK waters are returned to JNCC where, after appropriate quality checks, they are included in a database. Although MMOs only need to observe prior to firing commencing, most continue to observe at other times, including during soft starts and full power firing, hence the database includes a large amount of data providing a valuable resource for analysis.

This report presents the results of an analysis of that database, including all data from 1994, just prior to the introduction of the guidelines, until the end of 2010. Previous analyses have analysed subsets (one to four years) of these data (Stone 1997, 1998, 2000, 2001, 2003a, b, 2006; Stone and Tasker 2006), but analysis of the larger dataset increased sample sizes and permitted further statistical testing of more individual species. The aim of the analysis was to identify any effects of seismic operations on marine mammals and any long term trends in compliance with the JNCC guidelines. More specifically, the following comparisons were made:

- general trends in survey effort and species distribution;
- detection rates (firing versus not firing);
- detection rate trends throughout the duration of surveys;
- closest distance of approach to the airguns (firing versus not firing);
- behaviour;
- effectiveness of the soft start;
- general trends in compliance with the JNCC guidelines.

2 Methods

2.1 Marine mammal observations and effort

Marine mammal observations were undertaken from seismic 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. Data from 1994 until 2010 were recorded; although the JNCC guidelines were not introduced until 1995 some companies started recording their observations while the guidelines were in preparation.

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 (http://jncc.defra.gov.uk/page-4703); the proportion of surveys with trained MMOs steadily increased over time. In addition PAM was utilised on some surveys during night-time operations and sometimes also during the day. In 1994 and 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. A number of 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 forms: ‘Cover Page’ (general information about the survey), ‘Operations’ (times of all airgun operations and associated mitigation), ‘Effort’ (details of visual and acoustic monitoring, including time, position, source activity and weather conditions) and ‘Sightings’ (details of any marine mammals encountered). When marine mammals were encountered observers recorded the species (with a supporting description), number of animals, behaviour, closest distance of approach to the airguns and the airgun activity at the time of the encounter. Photographs were sometimes taken to aid in confirmation of species identification. 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, but 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 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 Airgun arrays

The observations encompassed a range of types of seismic survey with widely varying sizes of airgun array. The smallest airgun array volume was 6 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 5,500 cu. in. Where appropriate, surveys with airguns of small volumes were analysed separately from those with larger airgun volumes with the split occurring at 500 cu. in. (following the threshold used in the JNCC guidelines to determine action during a line change). Therefore, in the context of this report, ‘large arrays’ refers to arrays with a volume of 500 cu. in. or more and ‘small arrays’ refers to arrays with a volume of less than 500 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 OBC surveys were assigned to the ‘large arrays’ category and site surveys were assigned to the ‘small arrays’ category, as the vast majority of these types of surveys consistently used airgun volumes in the respective category. VSP operations used airgun volumes ranging from 150 cu. in. to 1,200 cu. in. with a substantial proportion in each of the ‘large arrays’ and ‘small arrays’ categories. Therefore where airgun volume was not recorded, individual VSP operations were not included in any analysis where ‘large arrays’ and ‘small arrays’ were distinguished. The ‘small arrays’ category included 678 surveys, while 500 surveys used ‘large arrays’.

The frequency and source level of the airguns were often not recorded as this information was not requested on recording forms in earlier years. However, from available information ‘large arrays’ typically produce frequencies predominantly up to around 200Hz, with a peak-to-peak energy output from the source of around 130-140 bar metres, equating to a peak source level of around 256dB re. 1μPa @ 1m. ‘Small arrays’ (e.g. as used on site surveys) typically produce frequencies predominantly up to around 250Hz, with a peak-to-peak energy output from the source of around 10 bar metres, equating to a peak source level of around 235dB re. 1μPa @ 1m.

2.3 Data quality control

Only data of acceptable quality were entered into the database and were 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 airgun array 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. If data were accurate or minor inaccuracies were able to be corrected then the data were entered into the database. Data with key information missing or errors that were not able to be corrected were discarded; approximately 15% of surveys had at least part of the associated data discarded, although this happened slightly less often (11%) on surveys with ‘large arrays’ where dedicated MMOs were more often used. The recording forms have evolved over the years so it is not possible to make a meaningful comparison between years of the amount of data discarded.

After following the quality control process, data from a total of 1,196 surveys were entered into the database and were available for analysis, spanning the period from 1994 to 2010. Of the surveys included in the database, 91% were entirely in UK waters, 3% spanned both UK and adjacent waters and 6% were only in adjacent waters of neighbouring countries.

2.4 Analysis and statistical tests

For some analyses it was not appropriate to use all of 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 airgun 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, but when considering compliance with JNCC guidelines records from outside the UKCS were excluded.

Where airgun volume was likely to influence the results, surveys with ‘large arrays’ were analysed separately from surveys with ‘small arrays’ where possible. 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. Hammond *et al* 2013; Northridge *et al* 1995). 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 < 2m and visibility > 5km) were used. Location, season, observer ability and monitoring method (visual or acoustic) also needed to be considered as potential influences for some analyses. The following sections indicate how data was treated in order to reduce bias from these influences.

Non-parametric statistical tests were used throughout (Siegel and 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. Sometimes sample sizes were too small to be able to run the statistical test for individual species (this varied depending on the test being used), so groups of combined species were used, e.g. all seals, all cetaceans, all baleen whales, all beaked whales, all delphinids or all small odontocetes. These combined species groups comprised all identified and unidentified animals within that taxonomic grouping (Table 2.1), e.g. the baleen whale group included both fin whales and unidentified fin/ sei whales, amongst other species. The group of all small odontocetes included all the dolphin species (identified or unidentified) and the harbour porpoise. Combined species groups were more often used for surveys with 'small arrays' than those with 'large arrays', as surveys with 'small arrays' were often of short duration so sample sizes were lower. For surveys with 'large arrays' sample sizes were mostly greater, but beaked whales were combined due to low numbers of detections of individual species.

Table 2.1 Division of cetacean species into combined species groups for analysis (combined species groups also included unidentified animals within that group).

Baleen whales	Beaked whales	Delphinids	Small odontocetes
Northern right whale	Northern bottlenose whale	Long-finned pilot whale	Risso's dolphin
Humpback whale	Sowerby's beaked whale	Killer whale	Bottlenose dolphin
Blue whale		False killer whale	White-beaked dolphin
Fin whale		Risso's dolphin	Atlantic white-sided dolphin
Sei whale		Bottlenose dolphin	Short-beaked common dolphin
Minke whale		White-beaked dolphin	Striped dolphin
		Atlantic white-sided dolphin	Harbour porpoise
		Short-beaked 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 2.1. 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 (1^{o} latitude and longitude rectangle, comprising 30 licensing blocks) where the watch started. Individual species maps are included in Appendix 1. For rarer species (northern right whale, blue whale, Sowerby's beaked whale and false killer whale) 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 where shifts in distribution over time were apparent, 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 periods when the airguns were not firing during good observation conditions.

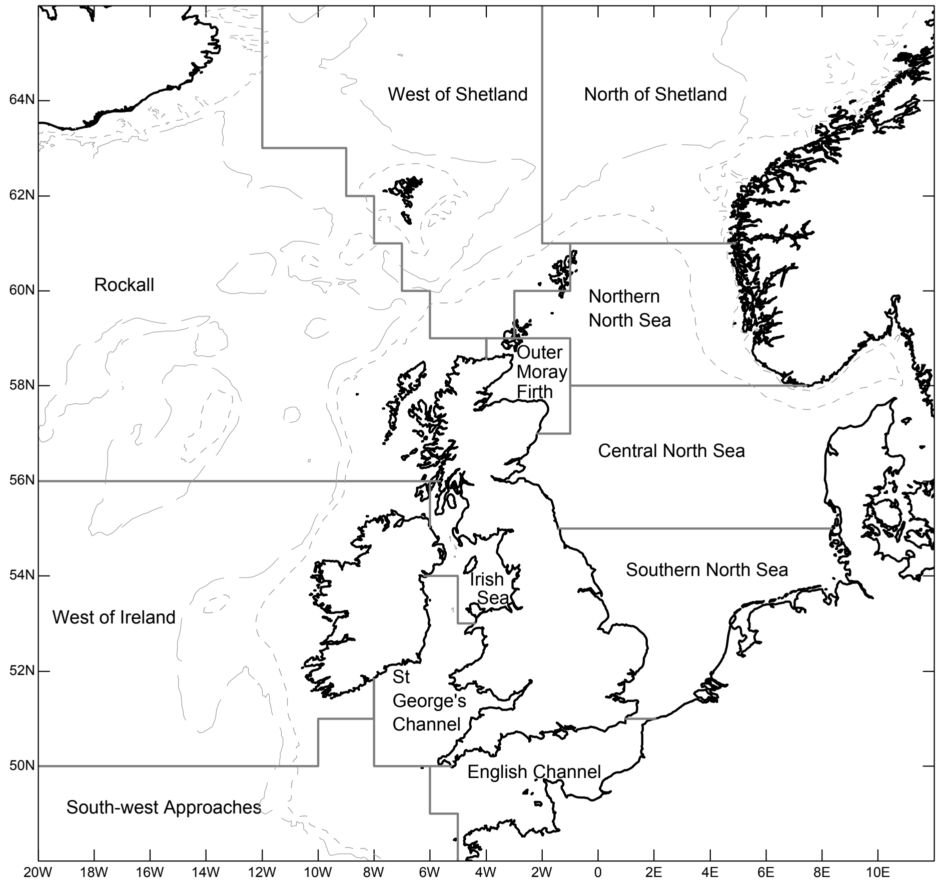

Figure 2.1. Geographic areas used in data analysis (short dashed line = 200m isobath; long dashed line = 1,000m isobath).

2.4.2 Detection rates (firing versus not firing)

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 airguns were regarded as firing whether they were firing at full power, undertaking a soft start, or firing at reduced power for some reason other than a soft start. Most effort when firing would have been at full power, as the soft start and other reduced power firing is of relatively short duration. As airgun volume was likely to influence the results, surveys with ‘large arrays’ were analysed separately from those with ‘small arrays’.

Detection rates may be influenced by other variables, e.g. location, season, weather, monitoring method and observer ability. Therefore matched pairs (firing versus not firing) were used where for each pair the survey, ship, date, observer, monitoring method (visual or acoustic) and weather conditions (sea state, swell and visibility) were the same, so the only remaining variable was the source activity (the combination of ship and date controlled for location within the range that could be travelled by a ship during the course of one day). The resulting matched pairs (firing versus not firing) 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 and 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 rate trends throughout the duration of surveys

Data from surveys lasting three weeks or longer were examined to see if there was any evidence of a decline in numbers of marine mammals after the survey commenced if activity was prolonged. Only surveys with 'small arrays' were considered as these were mostly site surveys where firing occurred within a small area (surveys with 'large arrays' often covered a wide area with temporal variation in the precise location of firing throughout the survey). Only surveys where the airguns became active during the first week were used.

The Wilcoxon signed ranks test was used to compare sighting rates between the first and later weeks of each survey. Comparing within each survey controlled for the influence of location and, to some extent, observer. Due to the nature of the question, seasonal variations may have had an influence, as numbers of animals may have naturally increased or decreased throughout the duration of each survey. The influence of monitoring method and weather were controlled by using only visual sightings during good observation conditions.

2.4.4 Closest distance of approach to the airguns (firing versus not firing)

The airguns were regarded as firing whether they were firing at full power, undertaking a soft start or firing at reduced power for some reason other than a soft start. As airgun volume was likely to influence the results, surveys with 'large arrays' were analysed separately from those with 'small arrays'. Distance estimation with PAM was not as accurate as with visual monitoring (Stone 2015), so only visual detections (with or without accompanying effort data) were used to compare the closest distance of approach to the airguns. Airguns were less likely to be firing 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 airguns were not firing. This potential bias was controlled by using only sightings during good observation conditions. 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 airguns were not firing); this could also result in bias towards closer distances when the airguns were not firing. To reduce this potential bias only sightings by observers with good detection skills were used. An initial examination of data from a small sample of known experienced observers found that a minimum of 20% of detections were more than 1km away. This was applied as a criterion for selecting observers with good detection skills throughout the database; in order to determine which observers met this standard, only those who had at least 20 sightings were considered.

The closest distance of approach of animals to the airguns was compared (firing versus not firing) 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 and 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 airguns were regarded as firing whether they were firing at full power, undertaking a soft start or firing at reduced power for some reason other than a soft start. As airgun volume was likely to influence the results, surveys with ‘large arrays’ were analysed separately from those with ‘small arrays’.

The frequency of occurrence of each recorded behaviour was compared between periods of firing and not firing. 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 (firing versus not firing), for all behaviours and species where the expected frequency in both groups was at least five (Siegel and Castellan 1988). 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 and 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 airguns, and behaviour were compared for periods when the airguns were not firing, periods when they were firing at full power and periods when they were firing during the soft start. As the soft start is of relatively short duration sample sizes were often low; only three individual species (minke whale, white-beaked dolphin and Atlantic white-sided dolphin) could be examined, otherwise combinations of species were used.

Matched samples were used to compare detection rates at each source activity level during each day of each survey on each ship when monitoring method (visual or PAM) and weather conditions (sea state, swell, visibility and sun glare) were the same, thereby controlling for any influence of location, season, weather, type of survey, monitoring method and, to some extent, observer. Only surveys where effort during the soft start had been differentiated from effort at full power were used (July 2009 onwards). As this limited sample sizes all available data were used regardless of total airgun volume (both visual sightings and acoustic detections). 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 was 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.

The closest distance that marine mammals approached the airguns was compared using only visual sightings during good observation conditions, as PAM did not give accurate range estimation and weather may affect visual detection at distance. As sightings did not need to be effort-related records from all years could be used; this meant that sample sizes were sufficient to analyse surveys with 'large arrays' separately from those with 'small arrays'. The Kruskal-Wallis one-way analysis of variance by ranks was used; 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 used to determine where the significant differences lay.

Behaviour was compared using visual sightings where source activity did not change during the course of the encounter. All sightings from all years were used, regardless of observer or weather conditions (as weather was unlikely to influence the ability of the observer to record behaviour) or whether there was accompanying effort data. 'Large arrays' were analysed separately from 'small arrays'. 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.

The chi-squared test was also used to examine behaviour at the commencement of the soft start by comparing encounters where the airguns were not firing throughout, those where the soft start commenced during the course of the encounter or those where the airguns were performing a soft start throughout. The chi-squared test can only be performed if the expected frequency in all groups is at least five; diving was the only behaviour where this condition was met (only when surveys with arrays of any size were included).

2.4.7 General trends in compliance with the JNCC guidelines

Three key areas of compliance with the guidelines were compared over time. These were the number of visual pre-shooting searches during daylight hours that were at least 30 minutes long (or 60 minutes in deep waters since June 2009), the number of soft starts that were at least 20 minutes long and the proportion of delays that were correctly implemented (delay of at least 20 minutes plus subsequent soft start of at least 20 minutes). Compliance was compared as far back as records would allow; pre-shooting searches and soft starts were compared for all years since 1998 (when operations data were first recorded), while delays were compared since the introduction of the guidelines in 1995. Only data from the UKCS were analysed when assessing compliance with the JNCC guidelines.

3 Results

3.1 General trends in survey effort and species distribution

Observations for marine mammals were undertaken on seismic surveys throughout the UK and some adjacent waters, covering 199 quadrants (1^{o} rectangles = 30 licensing blocks), some of which were passed in transit to or from the survey location when airguns were not firing but sightings were still recorded. A total of 190,727 hours 54 minutes were recorded as monitoring for marine mammals between 1996 and 2010 (effort was not recorded prior to 1996); of this, 181,119 hours 19 minutes were recorded for visual monitoring and 9,608 hours 35 minutes for acoustic monitoring. The airguns were firing for 38.8% of the total time spent monitoring.

All areas had at least some survey effort, with the exception of the English Channel (Figure 3.1). The majority of effort was in the central and northern North Sea, but there was also substantial effort in the southern North Sea and to the west and north of Shetland. There was comparatively little PAM effort, with PAM being adopted as a mitigation measure gradually over the years. PAM effort was concentrated in the northern and central North Sea (particularly the Outer Moray Firth and adjacent waters) and waters to the west and north of Shetland, reflecting its use in sensitive areas. The maps only show effort where it was correctly recorded on the ‘Effort’ form (or ‘Location and Effort’ form in earlier years), hence a small number of surveys with PAM in the central North Sea, the Rockall Trough and St George’s Channel are not illustrated on the map.

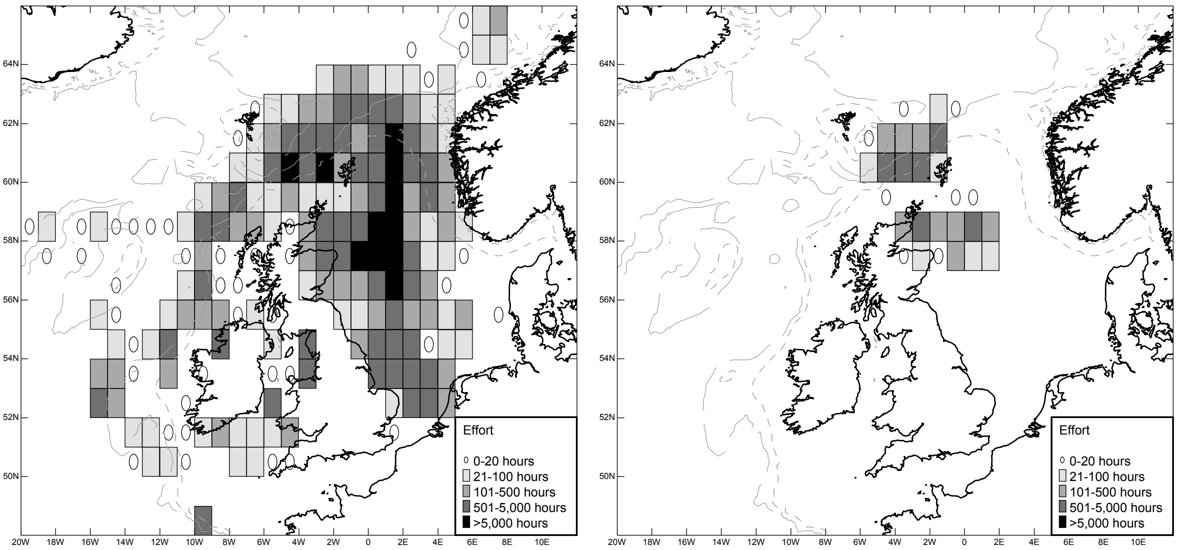

Figure 3.1. Visual effort (left) and PAM effort (right) during seismic surveys from 1996-2010 (short dashed line = 200m isobath; long dashed line = 1,000m isobath).

PAM effort was seldom recorded prior to 2006, so visual effort and PAM effort were combined together when considering the variation in effort over time. In the period from 1996-2000 there were many surveys in deep water areas to the west of Shetland and in the Rockall Trough (corresponding with the 16th and 17th rounds of offshore oil and gas licensing) and extending down through deep waters to the west of Britain and Ireland (Figure 3.2). Between 2001 and 2005 there were fewer surveys in these deep water areas, while between 2006 and 2010 there was another increase in effort to the west of Shetland and lower effort extending out over banks to the west of the Rockall Trough.

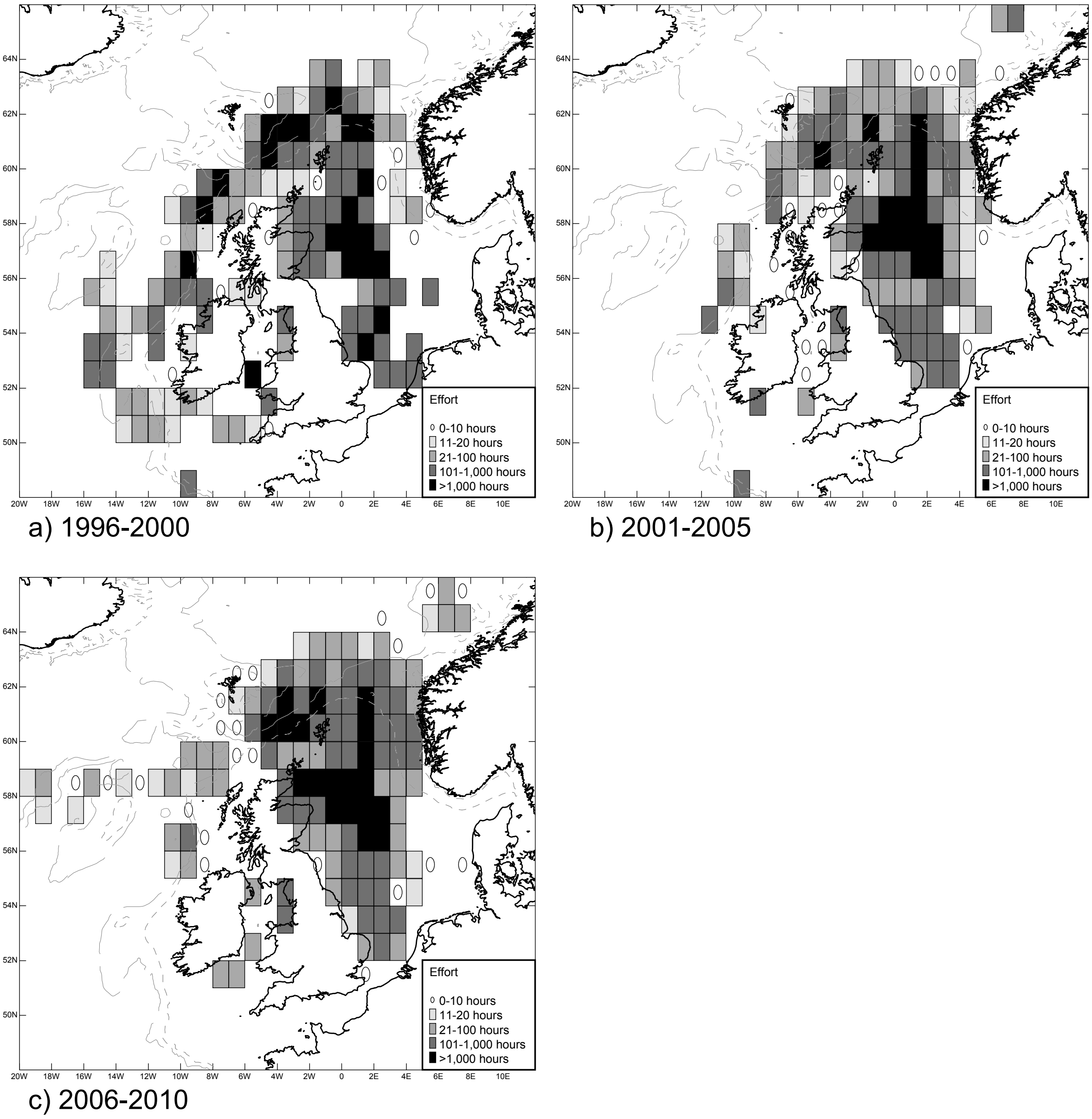

Figure 3.2. Effort (visual and PAM) during seismic surveys at different time periods (short dashed line = 200m isobath; long dashed line = 1,000m isobath).

Visual effort was mainly confined to the North Sea during the first quarter of the year, but was much more widespread during the second and third quarters, when weather conditions are usually more favourable for surveying in exposed areas such as deep waters to the west of Britain and Ireland (Figure 3.3). In the last quarter of the year conditions would again be expected to be suboptimal, but although surveying in deep water areas was limited, it was not as restricted as during the first quarter, probably due to unfinished surveys continuing from the summer months. Although visual effort was extensive in the North Sea throughout the year, the amount of effort was greatest in the second and third quarters and least in the first quarter. Visual effort is strongly influenced by available daylight, which is greatest in the second and third quarters and is particularly limited in northern areas during winter months, as well as by the extent of surveying.

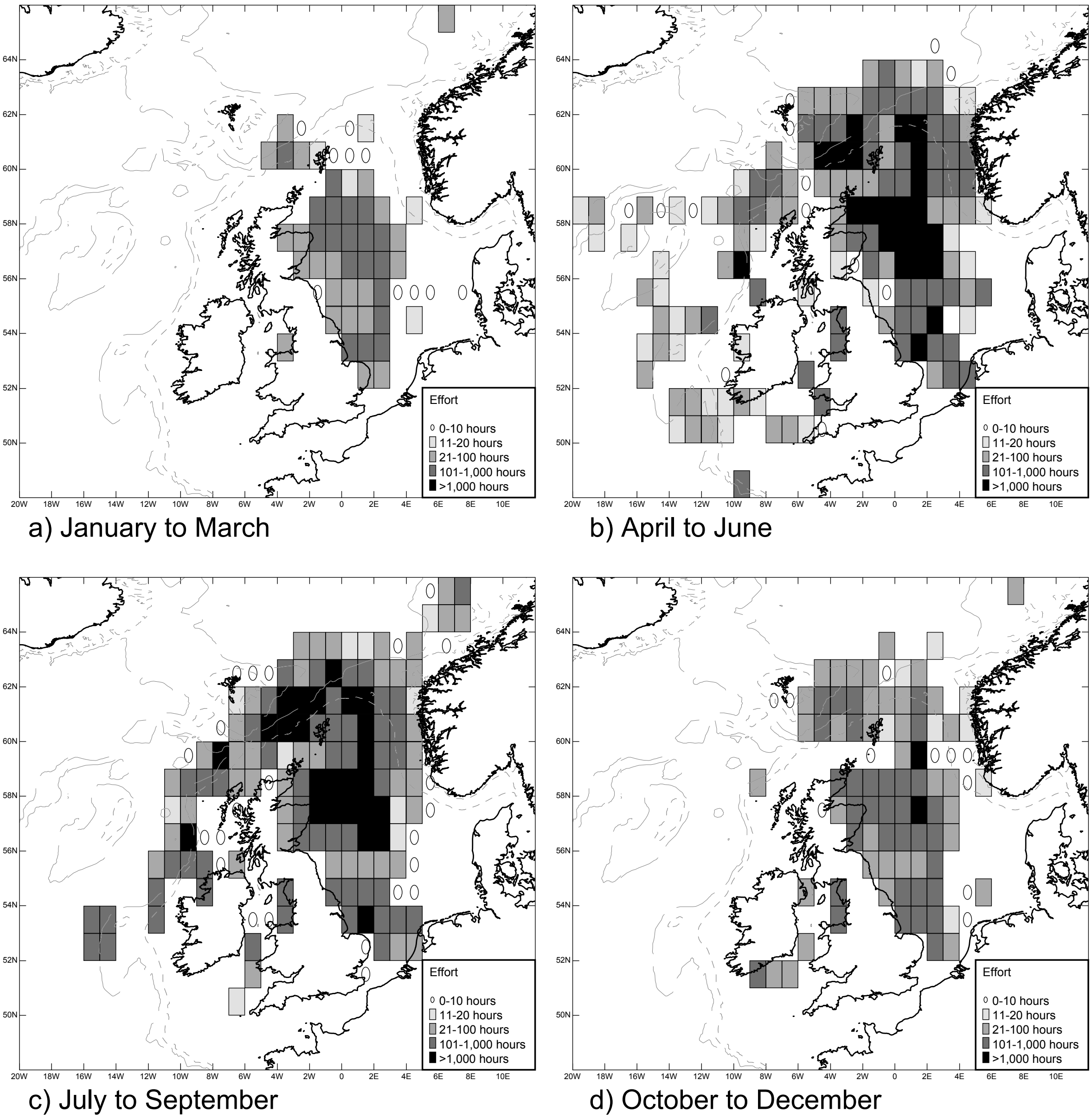

Figure 3.3. Visual effort by season during seismic surveys from 1996-2010 (short dashed line = 200m isobath; long dashed line = 1,000m isobath).

PAM effort continued to the west of Shetland throughout the year, although again it was reduced during the first quarter and greatest during the second and third quarters (Figure 3.4). PAM effort in the Outer Moray Firth and adjacent waters peaked during the third quarter.

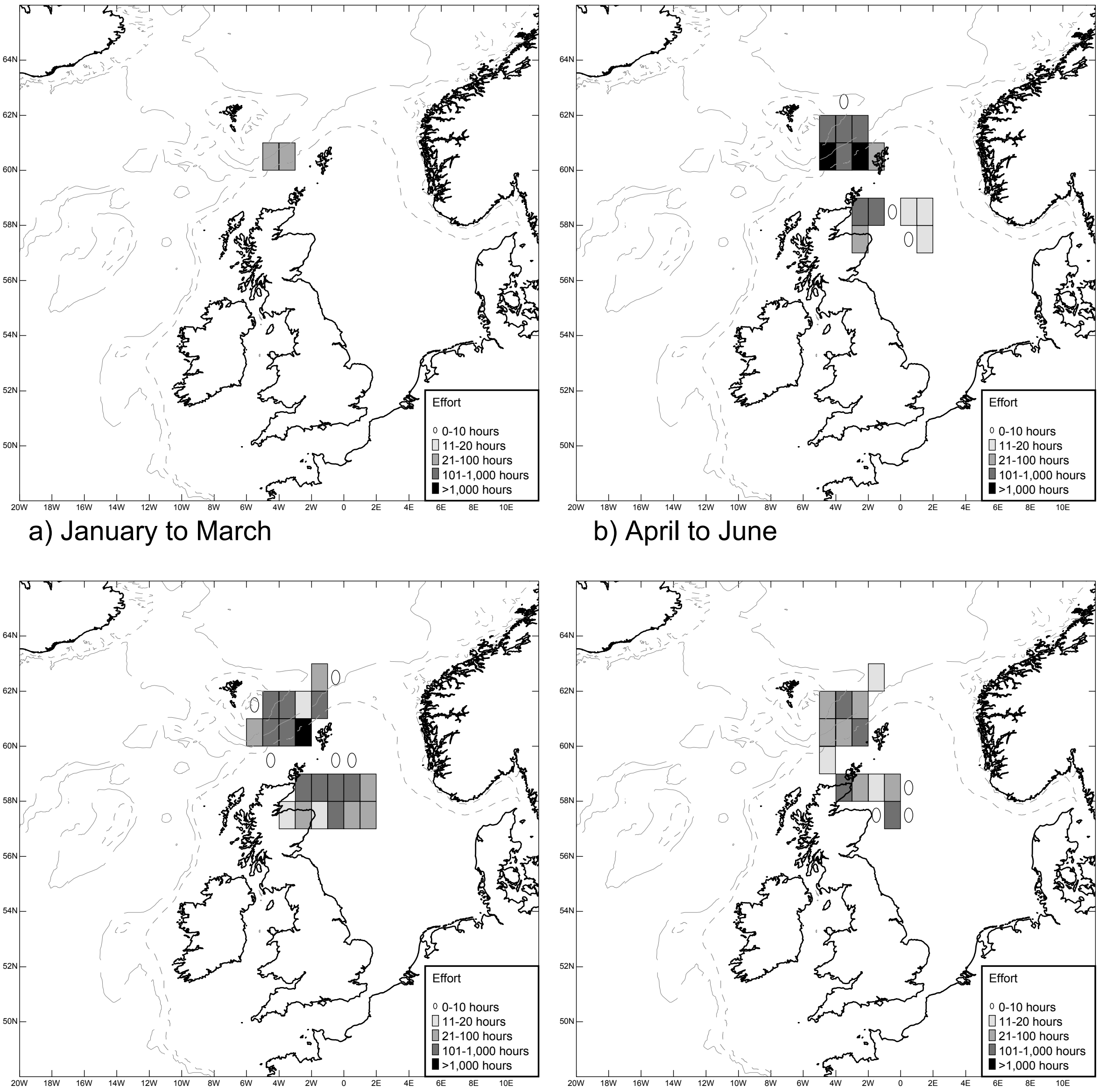

Figure 3.4. PAM effort by season during seismic surveys from 1996-2010 (short dashed line = 200m isobath; long dashed line = 1,000m isobath).

There were 9,073 sightings or acoustic detections of marine mammals during seismic surveys in UK and adjacent waters, comprising 124,024 individuals (Table 3.1). The most frequently encountered species of marine mammal identified was the white-beaked dolphin (an encounter being one or more animals occurring together). Atlantic white-sided dolphins, minke whales, sperm whales, harbour porpoises and long-finned pilot whales were also seen frequently, with fin whales, killer whales and short-beaked common dolphins seen moderately often. The most numerous species (number of individuals seen) was the Atlantic white-sided dolphin, followed by the white-beaked dolphin and then the long-finned pilot whale and short-beaked common dolphin, reflecting the often large number of animals in each pod of these species.

Multi-species associations were sometimes observed; 163 of the 9,073 sightings comprised more than one species. The species most commonly occurring in association with other species was the long-finned pilot whale (80 associations) followed by the Atlantic white-sided dolphin (66 associations). These two species together represented the most common combination of species found in association (35 associations). Long-finned pilot whales were also seen with unidentified dolphins on 28 occasions while Atlantic white-sided dolphins were also recorded as associating with fin whales (8 associations) and white-beaked dolphins (7 associations). Other combinations of species were recorded infrequently.

Table 3.1. Species of marine mammal encountered during seismic surveys in UK and adjacent waters from 1994-2010.

Species	No. sightings/ acoustic detections	No. individuals
Seal sp.	92	122
Grey seal	108	113
Harbour seal	23	24
Cetacean sp.	541	4,181
Whale sp.	301	681
Large whale sp.	207	425
Northern right whale (probable)	1	1
Humpback whale	22	48
Blue whale	13	14
Fin whale	342	789
Sei whale	23	34
Humpback/ sperm whale	21	26
Blue/ fin/ sei whale	18	30
Fin/ sei whale	127	252
Fin/ sei/ humpback whale	55	109
Fin/ sei/ blue/ humpback whale	169	370
Fin/ blue whale	42	83
Sperm whale	547	758
Medium whale sp.	81	133
Minke whale	724	854
Beaked whale sp.	9	21
Northern bottlenose whale	10	44
Minke/ northern bottlenose whale	1	1
Sowerby’s beaked whale	6	14
Long-finned pilot whale	485	9,321
Killer whale	332	2,229
False killer whale	1	7
Long-finned pilot/ false killer whale	2	7
False killer whale/ killer whale/ Risso’s dolphin	1	2
Delphinid sp. (dolphin, long-finned pilot, killer, false killer whale)	9	9
Dolphin sp.	1,614	20,451
Dolphin sp. (not porpoise)	65	550
Unpatterned dolphin (Risso’s/ bottlenose)	5	28
Risso’s dolphin	81	716
Bottlenose dolphin	101	1,349
Patterned dolphin (common/ striped/ white-beaked/ Atlantic white-sided)	108	2,328
White-beaked dolphin	1,166	16,169
Atlantic white-sided dolphin	727	45,926
Lagenorhynchus sp.	175	5,740
Short-beaked common dolphin	315	8,205
Striped dolphin	10	427
Short-beaked common/ striped dolphin	5	39
Short-beaked common/ striped/ Atlantic white-sided dolphin	1	4
Short-beaked common/ Atlantic white-sided dolphin	20	267
Harbour porpoise	539	1,123
Total	**9,073***	**124,024**

*includes some mixed species sightings

The distribution of sightings and acoustic detections of marine mammals to a large extent reflected the location of surveys and the amount of effort spent in observing or acoustic monitoring (Figure 3.5). There were many sightings and acoustic detections in the areas where there was most effort (the central and northern North Sea and to the west of Shetland). However, there were high numbers of sightings/ acoustic detections relative to effort throughout shelf edge and deep waters to the north and west of Britain and Ireland, in the Outer Moray Firth and in St George’s Channel. Conversely, there were low numbers of sightings relative to effort in the southern North Sea, most likely to be correlated with variation in the distribution of species.

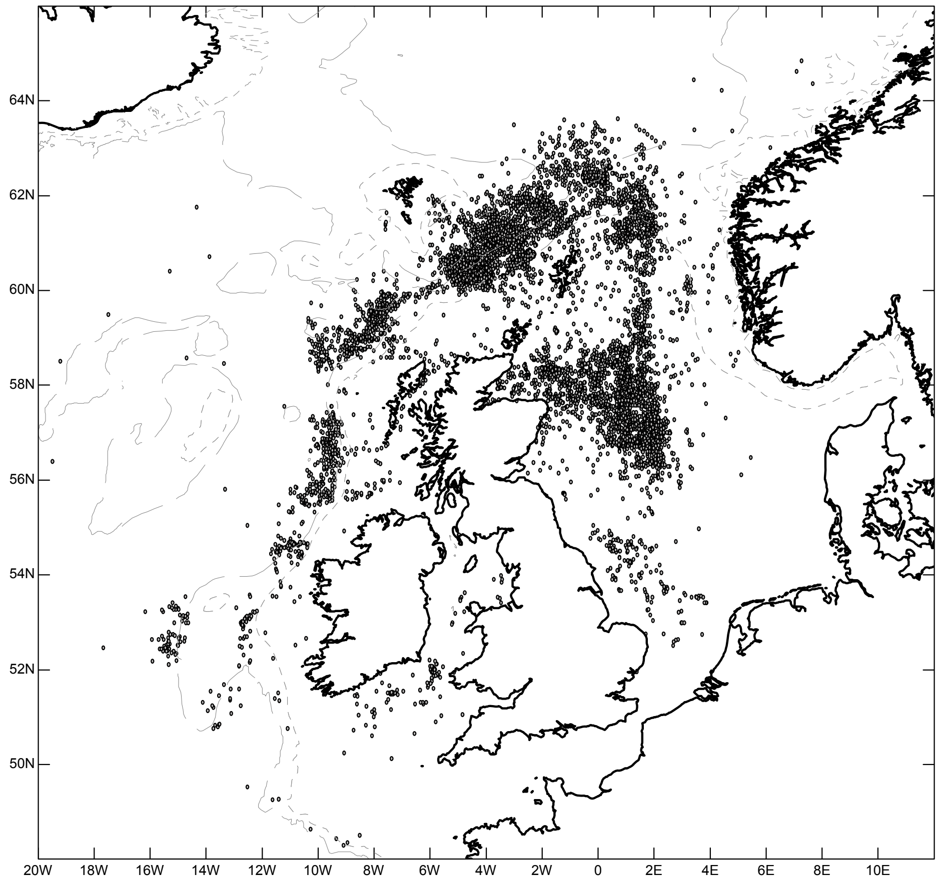

Figure 3.5. Sightings and acoustic detections of marine mammals during seismic surveys, 1994-2010 (short dashed line = 200m isobath; long dashed line = 1,000m isobath).

Individual species maps are included in Appendix 1 (Figure 8.1-Figure 8.19). The large rorqual whales (humpback, blue, fin and sei) were recorded mainly in deep waters and waters over the continental shelf edge (i.e. depths greater than 200m) to the north and west of Britain, with fin whales being the most commonly recorded of the large rorquals (Figure 8.1). In addition to sightings in deeper waters, there was also a sighting of a single fin whale in shelf waters to the east of Shetland and a single animal in the central North Sea (Figure 8.1). Also, a humpback whale was recorded close inshore on the east coast of Shetland (Figure 8.2) and there were occasional sightings of sei whales over the shelf to the north-east of Shetland (Figure 8.3). Few blue whales were seen, with all sightings being in shelf edge and deep waters (Figure 8.4) and there was a single sighting of a probable northern right whale near deep waters to the north of Shetland in 2000 (Figure 8.4). Minke whales, a medium-sized rorqual, were widespread throughout the central and northern North Sea and to the west of Shetland, in waters of all depths (Figure 8.5). Their distribution extended into the southern North Sea and to the west and south-west of Ireland.

Like the large rorqual whales, sperm whales were found in deep waters and waters over the continental shelf edge to the north and west of Britain, particularly in the Shetland-Faroes channel (Figure 8.6). There were also single sperm whales recorded in the central North Sea and in St George's Channel. Similarly northern bottlenose whales (Figure 8.7) and Sowerby's beaked whales (Figure 8.8) were also found in deep water and shelf edge areas in low numbers, although a single northern bottlenose whale was also seen close inshore off Aberdeen (Figure 8.7). Long-finned pilot whales were also distributed in deep waters and along the shelf edge, ranging throughout the area studied from the South-west Approaches to the north of Norway, although more were recorded in the northern half of the area (Figure 8.9). Their distribution also extended into the northern North Sea along the western edge of the Rinne (a channel between 200m and 500m depth that lies parallel to the south-western coast of Norway) and there were scattered occasional sightings over the shelf in the northern North Sea.

With the exception of some recorded in deep waters to the west of Ireland, all killer whales were recorded in the northern half of the area studied (Figure 8.10). There was a cluster of sightings of killer whales over the outer shelf and shelf edge to the north-east of Shetland and also a number of sightings over the shelf edge and deep waters to the west and north of Shetland. They were also recorded in lower numbers throughout the northern North Sea and Outer Moray Firth and extending into the central North Sea. There was one sighting of false killer whales to the west of Ireland (Figure 8.8).

Of the dolphin species, Risso's dolphins, Atlantic white-sided dolphins and striped dolphins seemed to prefer shelf edge and deep waters. Risso's dolphins were mainly recorded over the continental shelf edge to the west and north of Shetland, with some extending into deep waters and low numbers seen over the shelf edge to the west of Ireland (Figure 8.11). Scattered sightings also occurred in the Outer Moray Firth, the central and northern North Sea and St George's Channel. Atlantic white-sided dolphins were recorded frequently over the shelf edge and in deep waters to the west and north of Shetland and also over the outer shelf to the east of Shetland and along the western edge of the Rinne (Figure 8.12). A cluster of sightings also occurred in an area in the central and northern North Sea and Outer Moray Firth. Their distribution also extended along the shelf edge and deep waters to the west of Scotland and Ireland, with some sightings in shelf waters around the Hebrides. Striped dolphins were recorded infrequently, but mainly in deep waters to the west and north of Britain and Ireland (Figure 8.13). There was also one sighting in the central North Sea and one in the southern North Sea.

White-beaked dolphins were frequently recorded, with an apparent preference for shelf waters. Their distribution centred on an area in the central and northern North Sea and Outer Moray Firth, extending northwards from there over the outer shelf, shelf edge and deep waters to the west and north of Shetland and to a lesser extent southwards into the southern North Sea (Figure 8.14). There were scattered sightings in shelf waters to the west of Scotland and one sighting in St George's Channel. Harbour porpoises also seemed to prefer shelf waters, being widespread throughout the North Sea, including extending into the Moray Firth, but also extending in lower numbers into shelf edge and deeper waters to the north and west of Shetland (Figure 8.15). Low numbers were also recorded over the shelf to the west of Scotland, in the Irish Sea and St George's Channel.

Bottlenose dolphins and short-beaked common dolphins were more evenly split between shelf waters and the deeper waters over the shelf edge and beyond. Bottlenose dolphins mainly occurred in an area encompassing the central and northern North Sea and Outer Moray Firth and along the shelf edge and deep waters to the north and west of Britain and Ireland (Figure 8.16). Some were also recorded in St George's Channel and there were low numbers in the southern North Sea. Short-beaked common dolphins were frequently recorded in St George's Channel, but were also found over the outer shelf, shelf edge and deep waters from the west of Ireland to the north of Shetland (Figure 8.17). They were also recorded in the Outer Moray Firth and central and northern North Sea.

Grey seals were recorded throughout the Outer Moray Firth and the central and northern North Sea, often relatively close to land but also extending further offshore (Figure 8.18).

Low numbers were also recorded around Shetland, the southern North Sea and the Irish Sea. Harbour seals were recorded in the Outer Moray Firth and the northern North Sea, with low numbers in the southern and central North Sea (Figure 8.19).

Shifts in distribution over time were observed for fin whales and harbour porpoises. Fin whales were mainly encountered to the west of Shetland, but sighting rates were low in that area between 2006 and 2010 compared to previous years (Table 3.2). More harbour porpoises were recorded in the southern North Sea and fewer in the northern North Sea between 2006 and 2010 compared to previous years (Table 3.2). The distribution of other species both between years and throughout the year largely corresponded with the distribution of effort.

Table 3.2. Sighting rates of fin whales and harbour porpoises per 1,000 hours survey effort.

Species	Area	1996-2000	2001-2005	2006-2010
Fin whale				
	West of Shetland	25.97	17.63	1.77
Harbour porpoise				
	Northern North Sea	5.77	5.09	2.55
	Outer Moray Firth	0.00	7.57	6.71
	Central North Sea	1.69	6.01	4.54
	Southern North Sea	0.00	1.83	28.56

3.2 Effects of seismic operations on marine mammals

3.2.1 Detection rates (firing versus not firing)

On surveys with ‘large arrays’ detection rates were significantly higher when the airguns were not firing for the grey seal, minke whale, all beaked whales combined, killer whale, white-beaked dolphin, Atlantic white-sided dolphin and harbour porpoise (Figure 3.6Figure 3.6 and Table 3.3). On surveys with ‘small arrays’ detection rates were mostly similar whether the airguns were firing or not (Figure 3.7), but sperm whales and harbour porpoises were seen significantly less often when the airguns were firing (Table 3.3).

Table 3.3. Statistical significance of difference in detection rate of marine mammals in relation to airgun activity, using Wilcoxon signed ranks test (z = Wilcoxon statistic; for small samples T^+ = sum of ranks of pairs where detection rate when not firing exceeded detection rate when firing; n = sample size; P = probability; n.s. = not significant).

Species	z	T^+	N	P
'Large arrays'				
Grey seal	2.956	-	36	< 0.01
Harbour seal	-	25	9	n.s.
Humpback whale	-	16	7	n.s.
Fin whale	-0.444	-	103	n.s.
Sei whale	-	39	12	n.s.
Minke whale	3.093	-	281	< 0.001
All beaked whales	-	27	7	< 0.05
Sperm whale	1.528	-	116	n.s.
Long-finned pilot whale	0.639	-	127	n.s.
Killer whale	2.808	-	103	< 0.01
Risso's dolphin	1.039	-	31	n.s.
Bottlenose dolphin	1.176	-	31	n.s.
White-beaked dolphin	7.061	-	403	< 0.001
Atlantic white-sided dolphin	3.208	-	295	< 0.001
Short-beaked common dolphin	1.312	-	39	n.s.
Harbour porpoise	8.330	-	92	< 0.001
'Small arrays'				
All seals combined	-	5	7	n.s.
Grey seal	-	4	5	n.s.
All cetaceans combined	0.817	-	171	n.s.
All baleen whales combined	-1.272	-	32	n.s.
Minke whale	0.322	-	19	n.s.
Sperm whale	-	114	15	< 0.001
All delphinids combined	1.419	-	116	n.s.
Long-finned pilot whale	-	29	9	n.s.
Killer whale	-	7	5	n.s.
All small odontocetes combined	0.971	-	118	n.s.
Risso's dolphin	-	8	5	n.s.
White-beaked dolphin	0.327	-	18	n.s.
Atlantic white-sided dolphin	0.687	-	37	n.s.
Short-beaked common dolphin	-	10	6	n.s.
Harbour porpoise	-	21	6	< 0.05

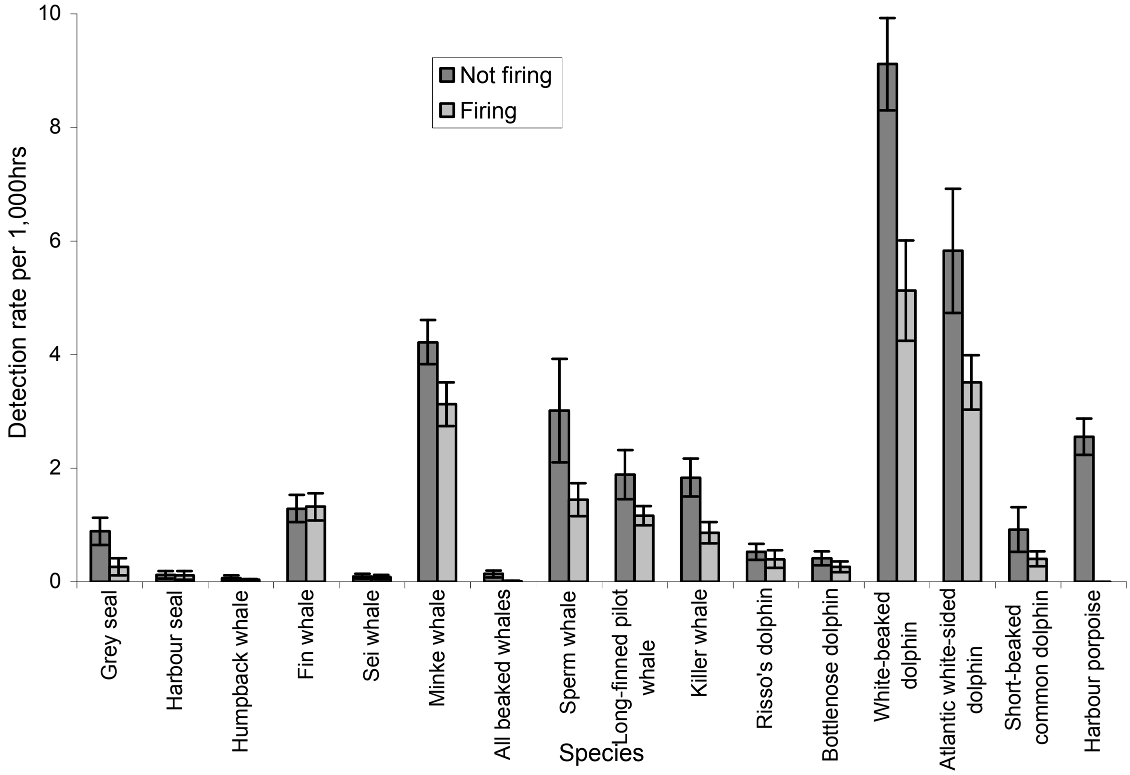

Figure 3.6. Mean detection rates (and standard error) of marine mammals in relation to airgun activity on surveys with 'large arrays'.

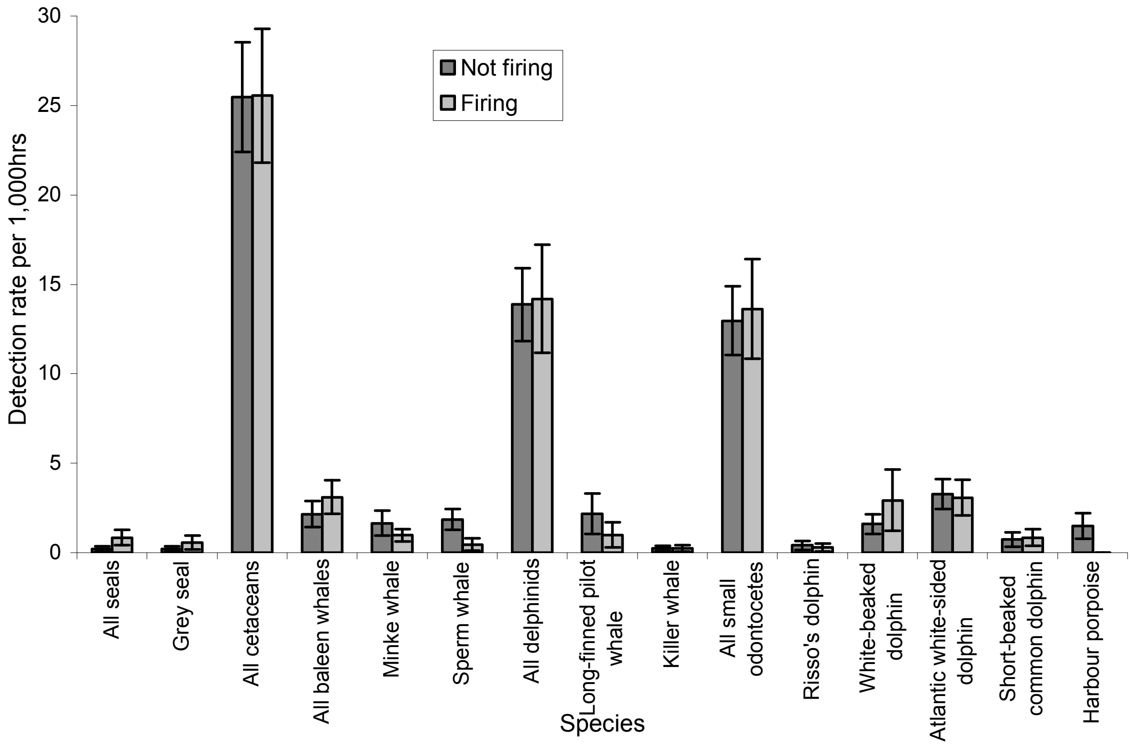

Figure 3.7. Mean detection rates (and standard error) of marine mammals in relation to airgun activity on surveys with 'small arrays'.

3.2.2 Detection rate trends throughout the duration of surveys

Surveys with ‘small arrays’, where firing tended to be concentrated within a small area, were generally of short duration, with 46% lasting less than one week and only 17% lasting three or more weeks. The amount of time spent firing in each week of each survey was hugely variable, depending on factors such as weather, technical problems and time-sharing etc. For those surveys with ‘small arrays’ that did last at least three weeks, sighting rates of delphinids and small odontocetes decreased significantly after the first week of the survey (Table 3.4, Figure 3.8).

Table 3.4. Statistical significance of difference in sighting rate of marine mammals between the first and later weeks of surveys with ‘small arrays’, using the Wilcoxon signed ranks test (for small samples T^+ = sum of ranks of pairs where sighting rate during week one exceeded that of later weeks; n = sample size; P = probability; n.s. = not significant).

Species	T^+	n	P
All cetaceans combined	39	10	n.s.
All baleen whales combined	11	5	n.s.
All delphinids combined	31	8	< 0.05
All small odontocetes combined	32	8	< 0.05
Harbour porpoise	11	5	n.s.

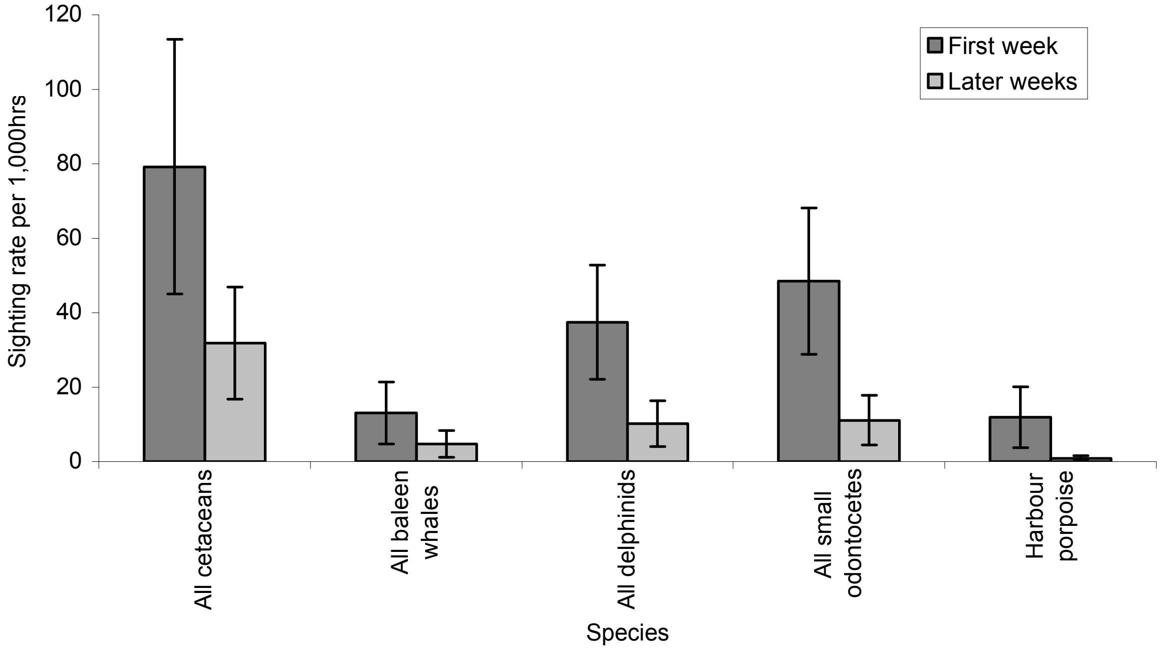

Figure 3.8. Mean sighting rate (and standard error) of marine mammals during the first week and later weeks of seismic surveys with ‘small arrays’.

3.2.3 Closest distance of approach to the airguns (firing versus not firing)

On surveys with ‘large arrays’, marine mammals often approached closer to the airguns when they were not firing than when they were firing (Figure 3.9). This difference was statistically significant for all baleen whales combined (although not for fin whales or minke whales, the only individual baleen whale species for which sample sizes were sufficient to test), killer whales, bottlenose dolphins, white-beaked dolphins, Atlantic white-sided dolphins and the harbour porpoise (Table 3.5). For species where the results were significant, the difference in the median closest distance of approach between when the airguns were firing and when they were not firing ranged between 300m (Atlantic white-sided dolphin) and 1,500m (bottlenose dolphin).

Conversely, on surveys with ‘small arrays’ marine mammals often approached closer to the airguns during periods when the airguns were firing than when they were not firing (Figure 3.10), but this was only statistically significant for all baleen whales combined (Table 3.5), which on average were over 1km further away when the airguns were not firing.

Table 3.5. Statistical significance of difference in closest distance of approach of marine mammals to the airguns in relation to airgun activity, using the Wilcoxon-Mann-Whitney test (z = Wilcoxon statistic; for small samples W_x = sum of ranks of the smallest group; n = sample size; P = probability; n.s. = not significant).

Species	z	Wx	n	P
‘Large arrays’				
Grey seal	0.000	-	27	n.s.
Harbour seal	-	33	10	n.s.
All baleen whales combined	9.283	-	477	< 0.001
Fin whale	1.382	-	107	n.s.
Minke whale	0.813	-	248	n.s.
Sperm whale	0.953	-	111	n.s.
Long-finned pilot whale	0.439	-	79	n.s.
Killer whale	2.099	-	81	< 0.05
Risso’s dolphin	-0.281	-	23	n.s.
Bottlenose dolphin	-1.799	-	12	< 0.05
White-beaked dolphin	6.075	-	302	< 0.001
Atlantic white-sided dolphin	3.133	-	213	< 0.001
Short-beaked common dolphin	1.420	-	16	n.s.
Harbour porpoise	3.065	-	126	< 0.01
‘Small arrays’				
All cetaceans combined	-0.953	-	136	n.s.
All baleen whales combined	-2.311	-	25	< 0.05
Minke whale	-0.187	-	14	n.s.
All delphinids combined	-0.428	-	66	n.s.
All small odontocetes combined	-0.530	-	72	n.s.
Atlantic white-sided dolphin	-0.147	-	18	n.s.

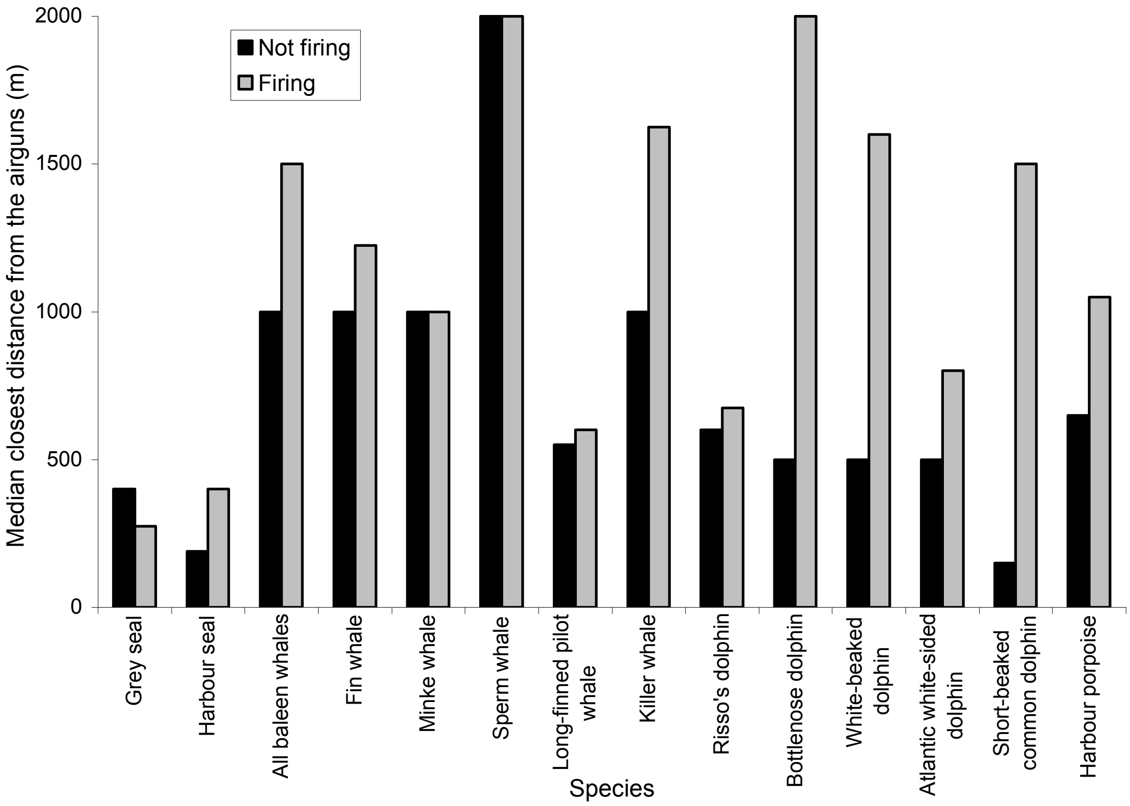

Figure 3.9. Median closest distance of marine mammals from the airguns in relation to airgun activity on surveys with 'large arrays'.

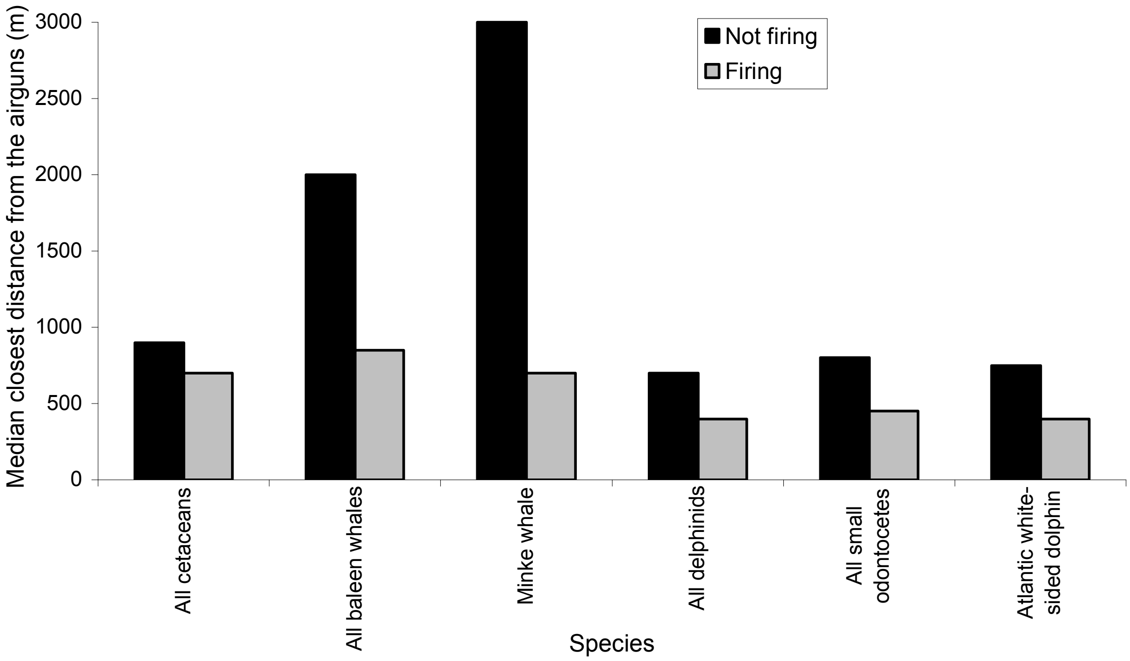

Figure 3.10. Median closest distance of marine mammals from the airguns in relation to airgun activity on surveys with 'small arrays'.

3.2.4 Behaviour

Firing of 'large arrays' affected the movement of cetaceans around the vessel (Table 3.6). Long-finned pilot whales, white-beaked dolphins and the combined groups of all delphinids and all small odontocetes engaged in positive interactions with the vessel or its equipment (e.g. bow-riding, approaching close to the vessel) or travelled towards the vessel more often when the airguns were silent. On surveys with 'large arrays', significantly more pods of fin whales, minke whales, long-finned pilot whales, white-beaked dolphins, Atlantic white-sided dolphins and harbour porpoises avoided or travelled away from the vessel during periods when the airguns were firing compared to when they were not firing. Minke whales, long-finned pilot whales and *Lagenorhynchus* spp. also altered course (in any direction, not necessarily to avoid the vessel) more often when the airguns were firing.

Minke whales, bottlenose dolphins, white-beaked dolphins and short-beaked common dolphins were more often recorded as swimming fast when 'large arrays' were firing and similarly *Lagenorhynchus* spp. and all baleen whales combined were more often recorded as swimming slowly when the airguns were not firing (Table 3.6). Conversely, long-finned pilot whales were more often recorded as swimming slowly when the airguns were firing. Bottlenose dolphins were more likely to breach or jump when the airguns were firing and white-beaked dolphins were more often recorded as splashing when the airguns were firing (often concurrent with fast swimming). When all cetaceans were combined fewer were porpoising during periods of firing. There was no apparent effect of firing on the tendency of cetaceans to swim in close groups or more widely spread groups, nor was there any correlation with tail-slapping or spy-hopping. The predominant behaviours exhibited by seals were bottling, diving or slow swimming but there was no significant difference in the prevalence of these behaviours in relation to airgun activity.

Other effects on surfacing/ diving behaviours were also apparent. There were indications that cetaceans may have remained close to the water surface when 'large arrays' were active. All cetaceans combined, all baleen whales combined and minke whales were more often recorded as surfacing frequently during periods when 'large arrays' were firing (Table 3.6). Although minke whales and other baleen whales contributed to the result for all cetaceans, these were not the only species recorded as surfacing frequently. Similarly, when all cetaceans were combined more were found to be logging or apparently resting at the surface when 'large arrays' were firing. Milling, where animals continue to surface in the same general vicinity, was more prevalent in baleen whales during periods of firing. A group including all delphinids were more often recorded both as diving and logging/ resting during periods of firing (although neither behaviour was observed more often during firing in those delphinid species that were able to be tested individually).

Cetaceans were sometimes recorded as feeding, although those animals showing behaviours indicative of feeding (e.g. holding a fish, lunging, or erratic swimming with birds diving alongside) would represent only a proportion of the animals actually feeding. Most species were recorded as feeding less often when 'large arrays' were firing (Table 3.6). Whilst the difference was not statistically significant for individual species, it was when all cetaceans were combined. This result was heavily influenced by delphinid species, but other species (e.g. fin whale, minke whale, harbour porpoise) were also observed feeding and contributed to the result.

Fewer effects on behaviour were evident with 'small arrays'. When species were combined it was apparent that positive interactions with the vessel or its equipment or travel towards the vessel occurred more often when the airguns were not firing, while avoidance or travel away was more prevalent when the airguns were firing (Table 3.6). While with 'large arrays' there were some indications that cetaceans may sometimes remain near the surface when the airguns are firing, with 'small arrays' cetaceans (all species combined) were more often recorded as surfacing infrequently during periods of firing, i.e. they were remaining submerged more.

Table 3.6. Behaviour of marine mammals in relation to airgun activity (n = sample size; P = probability; n.s. = not significant).

Behaviour	Species	% of encounters while firing when behaviour was exhibited	% of encounters while not firing when behaviour was exhibited	χ^2	n	P
'Large arrays'						
Altered course	Fin whale	8.3	4.5	1.89	20	n.s.
	Minke whale	4.7	1.7	4.85	17	< 0.05
	Long-finned pilot whale	13.0	5.9	6.02	41	< 0.05
	Lagenorhynchus spp.	4.4	1.5	13.04	43	< 0.001
	Atlantic white-sided dolphin	5.6	3.0	2.32	24	n.s.
Avoidance or travel away from vessel/ equipment	Fin whale	24.3	14.6	3.95	61	< 0.05
	Minke whale	16.3	8.2	8.44	70	< 0.01
	Sperm whale	19.7	18.7	0.05	68	n.s.
	Long-finned pilot whale	13.9	5.1	9.49	41	< 0.01
	Killer whale	18.1	11.9	1.70	41	n.s.
	White-beaked dolphin	19.2	8.2	22.24	115	< 0.001
	Atlantic white-sided dolphin	12.2	6.3	5.80	51	< 0.05
	Harbour porpoise	37.5	20.0	7.78	82	< 0.01
Bottling	Grey seal	36.8	31.3	0.14	28	n.s.
Breaching, jumping, somersaulting	Minke whale	8.4	5.9	1.31	43	n.s.
	Long-finned pilot whale	4.3	5.9	0.53	23	n.s.
	Killer whale	12.1	7.8	1.24	27	n.s.
	Risso's dolphin	33.3	16.3	2.01	15	n.s.
	Bottlenose dolphin	69.2	32.1	5.43	33	< 0.05
	Lagenorhynchus spp.	41.8	37.5	1.80	706	n.s.
	White-beaked dolphin	38.8	33.2	1.84	359	n.s.
	Atlantic white-sided dolphin	46.4	44.6	0.10	282	n.s.
	Short-beaked common dolphin	40.0	25.7	1.96	68	n.s.
Close group	Long-finned pilot whale	2.4	3.0	0.12	12	n.s.
	White-beaked dolphin	2.5	2.1	0.17	23	n.s.
	Atlantic white-sided dolphin	3.1	3.5	0.08	21	n.s.
Dispersed group	Long-finned pilot whale	5.3	2.5	2.20	17	n.s.
	White-beaked dolphin	3.3	3.0	0.04	32	n.s.
	Atlantic white-sided dolphin	7.1	12.6	3.70	68	n.s.
Diving	Grey seal	47.4	25.4	2.38	26	n.s.
	Fin whale	12.5	11.2	0.11	38	n.s.
	Minke whale	7.0	10.4	1.77	59	n.s.
	Sperm whale	43.0	50.0	0.90	168	n.s.
	All delphinids combined	2.2	1.4	4.10	75	< 0.05
	Long-finned pilot whale	5.8	3.4	1.41	20	n.s.
	Lagenorhynchus spp.	1.3	1.2	0.04	23	n.s.
Fast swimming	Fin whale	9.7	5.6	1.80	322	n.s.
	Minke whale	20.5	8.2	17.30	79	< 0.001
	Long-finned pilot whale	14.4	10.6	1.34	55	n.s.
	Killer whale	20.5	11.4	3.56	42	n.s.
	Bottlenose dolphin	46.2	18.9	4.66	22	< 0.05
	White-beaked dolphin	33.3	25.7	4.31	287	< 0.05
	Atlantic white-sided dolphin	53.1	45.3	1.68	298	n.s.
	Short-beaked common dolphin	63.3	24.3	13.83	72	< 0.001
	Harbour porpoise	26.3	20.0	1.11	73	n.s.
Feeding	All cetaceans combined	8.2	10.3	7.85	706	< 0.01
	Fin whale	9.7	12.9	0.71	37	n.s.
	Minke whale	0.9	3.1	2.76	15	n.s.
	Long-finned pilot whale	6.3	8.0	0.48	32	n.s.
	Killer whale	16.9	26.5	2.34	72	n.s.
	White-beaked dolphin	12.3	11.1	0.28	118	n.s.
	Atlantic white-sided dolphin	19.9	23.4	0.73	139	n.s.
In subgroups	All cetaceans combined	0.3	0.5	0.78	31	n.s.
	All delphinids combined	0.5	0.7	0.56	29	n.s.
	Lagenorhynchus spp.	1.0	1.1	0.05	19	n.s.
Logging/ resting	All cetaceans combined	3.7	2.6	6.81	216	< 0.01
	Sperm whale	35.9	29.9	0.95	115	n.s.
	All delphinids combined	2.1	1.3	4.18	72	< 0.05
	Long-finned pilot whale	8.7	8.9	0.01	39	n.s.
	All small odontocetes combined	1.0	0.8	0.31	33	n.s.

Behaviour	Species	% of encounters while firing when behaviour was exhibited	% of encounters while not firing when behaviour was exhibited	χ^2	n	P
Milling	All baleen whales combined	3.0	0.7	10.16	22	< 0.001
	Lagenorhynchus spp.	2.5	3.1	0.43	53	n.s.
	White-beaked dolphin	2.5	3.2	0.26	31	n.s.
	Atlantic white-sided dolphin	3.1	2.8	0.03	18	n.s.
Porpoising	All cetaceans combined	8.3	10.0	5.49	694	< 0.05
	Long-finned pilot whale	4.3	5.1	0.13	21	n.s.
	White-beaked dolphin	16.7	12.9	2.04	144	n.s.
	Atlantic white-sided dolphin	28.1	33.4	1.21	198	n.s.
	Short-beaked common dolphin	23.3	25.2	0.04	62	n.s.
Positive Interactions with or travel towards vessel/ equipment	All baleen whales combined	3.9	6.1	3.22	72	n.s.
	Minke whale	6.1	6.8	0.13	42	n.s.
	All delphinids combined	9.5	18.1	47.60	725	< 0.001
	All small odontocetes combined	8.9	18.3	45.26	613	< 0.001
	Long-finned pilot whale	15.4	27.0	6.93	96	< 0.01
	White-beaked dolphin	15.2	37.1	31.02	324	< 0.001
	Atlantic white-sided dolphin	7.7	13.1	3.48	71	n.s.
	Short-beaked common dolphin	23.3	25.7	0.06	63	n.s.
Resurfaced	All cetaceans combined	0.3	0.2	0.13	16	n.s.
Slow swimming	All seals combined	8.2	11.9	0.47	20	n.s.
	All baleen whales combined	19.0	24.2	4.02	304	< 0.05
	Fin whale	16.7	16.3	0.01	53	n.s.
	Minke whale	21.9	26.6	1.28	160	n.s.
	Sperm whale	21.8	18.7	0.42	71	n.s.
	Long-finned pilot whale	51.4	33.8	8.24	187	< 0.01
	Killer whale	20.5	25.6	0.64	73	n.s.
	Risso’s dolphin	50.0	34.9	0.87	27	n.s.
	Bottlenose dolphin	15.4	28.3	1.21	19	n.s.
	Lagenorhynchus spp.	6.9	12.3	10.04	196	< 0.01
	White-beaked dolphin	6.5	10.4	3.24	97	n.s.
	Atlantic white-sided dolphin	8.2	13.6	3.29	74	n.s.
	Harbour porpoise	32.5	26.2	0.89	94	n.s.
Splashing	White-beaked dolphin	8.7	4.5	6.45	58	< 0.05
	Atlantic white-sided dolphin	5.6	3.0	2.32	24	n.s.
Spy-hopping	Long-finned pilot whale	5.8	6.3	0.06	27	n.s.
Surfacing frequently	All cetaceans combined	1.6	1.0	6.30	87	< 0.05
	All baleen whales combined	4.8	2.2	7.07	44	< 0.01
	Minke whale	5.1	1.7	6.10	18	< 0.05
	All delphinids combined	0.4	0.5	0.11	22	n.s.
Surfacing infrequently	Fin whale	6.9	8.4	0.23	25	n.s.
	Minke whale	15.4	14.4	0.10	94	n.s.
	Sperm whale	4.9	2.8	1.05	13	n.s.
	Lagenorhynchus spp.	1.3	2.1	1.07	34	n.s.
	Harbour porpoise	7.5	6.5	0.08	23	n.s.
Swimming at or just below surface	All cetaceans combined	0.5	0.4	0.15	30	n.s.
Tail-slapping	Long-finned pilot whale	1.9	3.8	1.34	13	n.s.
	Lagenorhynchus spp.	1.0	1.7	1.34	27	n.s.
‘Small arrays’						
Avoidance or travel away from vessel/ equipment	All cetaceans combined	18.0	8.7	12.42	103	< 0.001
	All delphinids combined	17.3	6.7	11.27	51	< 0.001
	All small odontocetes combined	22.7	9.3	11.40	61	< 0.001
Breaching, jumping, somersaulting	All small odontocetes combined	34.1	24.6	2.56	138	n.s.
	Atlantic white-sided dolphin	42.3	33.3	0.43	35	n.s.
Diving	All cetaceans combined	6.6	7.2	0.09	70	n.s.
Fast swimming	White-beaked dolphin	46.7	33.0	0.71	45	n.s.
	Atlantic white-sided dolphin	46.2	33.3	0.86	36	n.s.
Feeding	All cetaceans combined	8.2	9.2	0.16	89	n.s.
	All small odontocetes combined	12.5	10.5	0.28	57	n.s.
Porpoising	All small odontocetes combined	17.1	10.7	2.53	62	n.s.
	Atlantic white-sided dolphin	19.2	23.6	0.16	22	n.s.

Behaviour	Species	% of encounters while firing when behaviour was exhibited	% of encounters while not firing when behaviour was exhibited	χ^2	n	P
Positive Interactions with or travel towards vessel/ equipment	All cetaceans combined	11.5	26.2	13.84	232	< 0.001
	All delphinids combined	11.6	36.1	16.35	190	< 0.001
	All small odontocetes combined	13.6	39.3	13.80	185	< 0.001
	Lagenorhynchus spp.	16.3	49.5	8.94	105	< 0.01
	White-beaked dolphin	46.7	67.0	0.84	84	n.s.
Slow swimming	All baleen whales combined	25.0	16.8	0.17	30	n.s.
	All small odontocetes combined	13.6	12.5	0.07	67	n.s.
Surfacing infrequently	All cetaceans combined	8.7	4.2	6.00	50	< 0.05

3.3 Effectiveness of the soft start

Detection rates differed significantly with source activity (not firing versus soft start versus full power) for all species or species groups that were able to be tested (Table 3.7). In all cases, detection rates during the soft start were significantly lower than when the airguns were not firing (Table 3.8, Figure 3.11). Although the mean detection rates for delphinids shown in Figure 3.11 are similar when the airguns were not firing and during the soft start, the Wilcoxon statistic measures both the direction and the magnitude of the difference and in this case the vast majority (83%) of samples had a lower detection rate during the soft start. Detection rates of baleen whales (all species combined) and minke whales were also lower during the soft start than when the airguns were firing at full power.

Table 3.7. Statistical significance of difference in detection rate of marine mammals in relation to airgun activity (differentiating the soft start from full power) using Friedman two-way analysis of variance by ranks (F_r = Friedman statistic; n = sample size; P = probability; n.s. = not significant).

Species	F_r	n	P
All cetaceans combined	36.873	723	< 0.001
All baleen whales combined	11.438	723	< 0.01
Minke whale	6.077	723	< 0.05
All delphinids combined	18.919	723	< 0.001
All small odontocetes combined	23.182	723	< 0.001
White-beaked dolphin	20.000	723	< 0.001
Atlantic white-sided dolphin	10.500	723	< 0.01

Table 3.8. Multiple comparisons of treatments using the Wilcoxon signed ranks tests (z = Wilcoxon statistic; T^+ = statistic for small samples; n = sample size; P = probability; n.s. = not significant).

	Not firing versus soft start			Soft start versus full power		
Species	z	n	P	z	n	P
All cetaceans combined	3.675	57	< 0.001	-1.301	34	n.s.
All baleen whales combined	$T^+ = 55$	10	< 0.001	$T^+ = 0$	8	< 0.01
Minke whale	$T^+ = 15$	5	< 0.05	$T^+ = 0$	5	< 0.05
All delphinids combined	2.651	41	< 0.01	-0.530	24	n.s.
All small odontocetes combined	3.238	39	< 0.001	-1.169	21	n.s.
White-beaked dolphin	$T^+ = 55$	10	< 0.001	-	0	-
Atlantic white-sided dolphin	$T^+ = 45$	9	< 0.01	$T^+ = 0$	3	n.s.

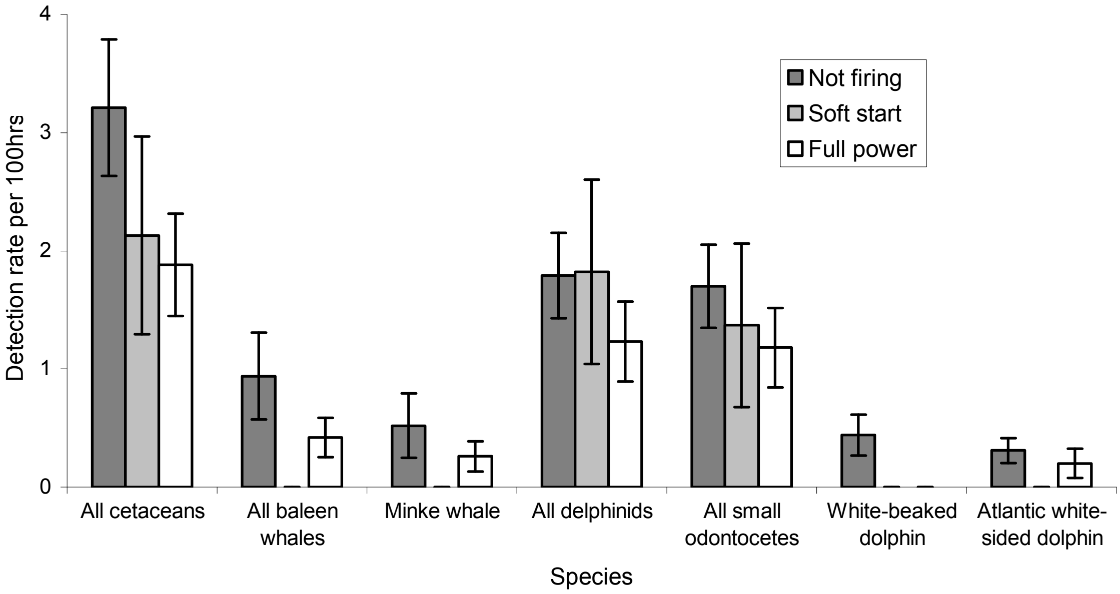

Figure 3.11. Mean detection rate (and standard error) of marine mammals in relation to airgun activity.

The closest distance that marine mammals approached the airguns differed significantly with source activity on surveys with 'large arrays' for the majority of species or species groups tested, with the exception of the minke whale (Table 3.9). Multiple comparisons of treatments to determine where the differences lay showed that for all species or species groups where the result was significant the closest distance during the soft start did not differ significantly from the closest distance at other times, but animals remained significantly further away from the airguns when they were firing at full power than when they were not firing (Figure 3.12). Sample sizes for surveys with 'small arrays' were lower, but when all cetaceans were combined there were no significant differences in the closest distance of approach with source activity (Table 3.9).

Table 3.9. Statistical significance of difference in closest distance of approach of marine mammals to the airguns in relation to airgun activity (not firing versus soft start versus full power) using the Kruskal-Wallis one-way analysis of variance by ranks (KW = Kruskal-Wallis statistic; n = sample size; P = probability; n.s. = not significant; degrees of freedom = 2 in all cases).

Species	KW	n	P
'Large arrays'			
All cetaceans combined	82.183	2,927	< 0.001
All baleen whales combined	20.898	613	< 0.001
Minke whale	5.965	342	n.s.
All delphinids combined	42.615	1,682	< 0.001
All small odontocetes combined	67.525	1,566	< 0.001
Lagenorhynchus spp.	62.672	721	< 0.001
White-beaked dolphin	44.825	391	< 0.001
Atlantic white-sided dolphin	18.045	263	< 0.001
'Small arrays'			
All cetaceans combined	4.061	296	n.s.

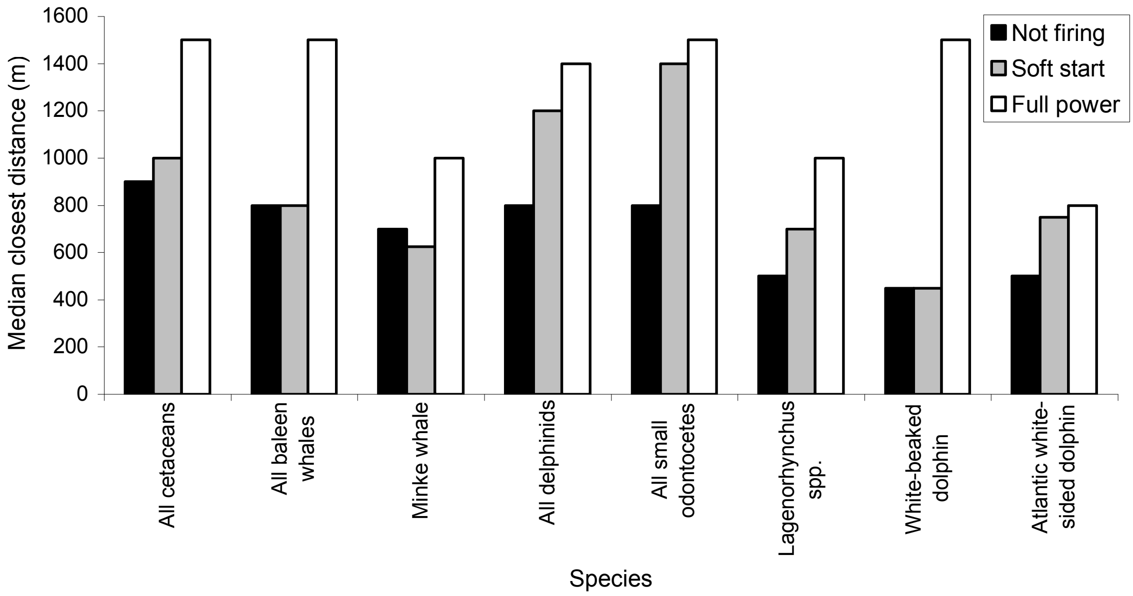

Figure 3.12. Median closest distance of approach of marine mammals to the airguns in relation to airgun activity (differentiating the soft start from full power) on surveys with 'large arrays'.

Some behaviours differed significantly with source activity on surveys with 'large arrays'. All species groups that could be tested showed an increased tendency to avoid or travel away from the vessel during the soft start than at any other time (Table 3.10), although not all animals did display such behaviours. All species and species groups tested also showed a reduced tendency to engage in positive interactions with the survey vessel or its equipment (e.g. bow-riding, etc.) or travel towards the vessel during the soft start than when the airguns were not firing and a further reduction when the airguns were firing at full power (Table 3.10). Some significant differences in swimming speed, aerial behaviours (such as breaching) and feeding were also apparent. It appeared that the soft start elicited increased avoidance and a decrease in positive interactions with the vessel or its equipment and in some cases also an increase in swimming speed (or fewer slow swimming behaviours). At full power positive interactions declined further, with some further increases in swimming speed, cetaceans (all species combined) engaged in feeding less often and small odontocetes were more likely to exhibit aerial behaviours. On surveys with 'small arrays' cetaceans (all species combined) again showed a reduced tendency to engage in positive interactions with the survey vessel or its equipment or travel towards the vessel during the soft start than when the airguns were not firing and a further reduction when the airguns were firing at full power (Table 3.10).

Table 3.10. Behaviour of marine mammals in relation to source activity (differentiating the soft start from full power) (n = sample size; P = probability; n.s. = not significant; d.f. = 2 in all cases).

Behaviour and Species	% of encounters while not firing when behaviour was exhibited	% of encounters during soft start when behaviour was exhibited	% of encounters while firing at full power when behaviour was exhibited	χ^2	n	P
'Large arrays'						
Avoidance or travel away from vessel						
All cetaceans combined	10.0	20.5	17.9	88.25	975	< 0.001
All delphinids combined	8.3	18.5	16.4	61.72	484	< 0.001
All small odontocetes combined	8.9	22.4	17.7	65.28	483	< 0.001
Lagenorhynchus spp.	7.7	24.5	16.9	35.68	186	< 0.001
Breaching, jumping or somersaulting						
All cetaceans combined	19.2	19.9	19.6	0.15	1,491	n.s.
All delphinids combined	28.9	29.6	31.3	1.71	1,321	n.s.
All small odontocetes combined	28.5	28.0	35.6	14.78	1,272	< 0.001
Lagenorhynchus spp.	37.4	32.7	41.9	2.21	679	n.s.
White-beaked dolphin	33.0	26.9	38.8	2.16	346	n.s.
Atlantic white-sided dolphin	44.8	41.2	46.8	0.17	271	n.s.
Dived						
All cetaceans combined	5.3	8.5	6.0	3.82	432	n.s.
Feeding						
All cetaceans combined	9.4	9.1	7.1	9.89	669	< 0.01
All delphinids combined	13.1	11.1	11.1	2.82	555	n.s.
All small odontocetes combined	11.3	10.3	11.5	0.15	475	n.s.
Lagenorhynchus spp.	14.4	12.2	15.1	0.28	257	n.s.
Positive interactions or travel towards the vessel						
All cetaceans combined	13.5	10.2	6.7	66.92	873	< 0.001
All delphinids combined	18.9	12.0	9.2	54.51	710	< 0.001
All small odontocetes combined	16.7	11.2	7.9	43.60	600	< 0.001
Lagenorhynchus spp.	27.3	18.4	9.2	39.71	404	< 0.001
White-beaked dolphin	36.9	26.9	13.3	32.65	314	< 0.001
Swimming fast						
All cetaceans combined	18.9	26.1	21.8	10.23	1,541	< 0.01
All delphinids combined	26.3	27.8	31.3	8.07	1,239	< 0.05
All small odontocetes combined	26.9	31.8	34.7	16.97	1,218	< 0.001
Lagenorhynchus spp.	33.6	30.6	42.4	7.50	632	< 0.05
White-beaked dolphin	25.5	26.9	33.8	4.50	278	n.s.
Atlantic white-sided dolphin	46.3	41.2	52.7	1.20	287	n.s.
Swimming slowly						
All cetaceans combined	15.4	11.9	16.2	2.21	1,201	n.s.
All baleen whales combined	24.3	10.0	19.8	4.78	299	n.s.
All delphinids combined	13.9	10.2	15.8	4.09	639	n.s.
All small odontocetes combined	11.9	10.3	9.6	3.90	473	n.s.
Lagenorhynchus spp.	12.2	4.1	6.7	11.53	186	< 0.01
'Small arrays'						
Positive interactions or travel towards the vessel						
All cetaceans combined	25.4	12.0	9.0	18.93	227	< 0.001

There were 84 encounters where marine mammals were first detected when the airguns were not firing but were still present when the soft start commenced. On 15 of these encounters (18%) responses were observed concurrent with the soft start commencing that could constitute a startle response. These responses included altering course to avoid the vessel, increasing swimming speed, diving, resurfacing after having dived, leaping, porpoising, spy-hopping, raising tail flukes and disappearing. Although there was one instance where animals that initially moved away at the onset of the soft start subsequently re-approached, there was no evidence that returning towards the vessel during the soft start was a common occurrence. Observed responses were not always consistent, demonstrating that different individuals may respond differently, e.g. one sperm whale was observed to dive when the soft start commenced while on another occasion a sperm whale that had recently dived was observed to re-surface and proceeded to swim at speed along the surface. Responses were observed both close to and further away from the airguns, up to 3km away.

In some other cases behaviours such as avoidance of the vessel, spy-hopping and tail-slapping were recorded but it was not made clear whether this was before or after the soft start began. Equally some animals were recorded as bow-riding but again it was unclear whether this was before or during the soft start. Diving was the only behaviour where sample sizes were sufficient to test the prevalence of the behaviour between encounters where the airguns were not firing throughout, those where the soft start commenced during the course of the encounter or those where the airguns were performing a soft start throughout (surveys with arrays of any size were included). More cetaceans were observed to dive if the soft start commenced during the encounter, with the difference being statistically significant (Table 3.11).

Table 3.11. Behaviour of marine mammals in relation to whether the soft start commenced during the encounter or not (n = sample size; P = probability; d.f. = 2).

Behaviour and Species	% of encounters while not firing when behaviour was exhibited	% of encounters during which the soft start commenced when behaviour was exhibited	% of encounters wholly during soft start when behaviour was exhibited	χ^2	n	P
Dived						
All cetaceans combined	5.7	10.3	9.0	6.67	358	< 0.05

3.4 General trends in compliance with the JNCC guidelines

The proportion of pre-shooting searches of adequate duration (at least 30 minutes, or at least 60 minutes in deep waters since 2009) has shown no major trends over time, ranging between 76% and 93%. The proportion of adequate soft starts has shown an increase since 2004 when alternative methods of performing a soft start were introduced for site surveys and VSP operations (Figure 3.13). Prior to this, on most site surveys no soft start was undertaken, even though this was not always agreed with the regulator and JNCC, hence the need for the guideline revisions to offer alternative soft start methods for such survey types.

There were 165 occasions when firing was required to be delayed in UK waters since the introduction of the guidelines in 1995 until the end of 2010. Delays were required most often due to the presence of white-beaked dolphins or Atlantic white-sided dolphins (the two species sighted overall most commonly from seismic survey vessels) in the mitigation zone, followed by unidentified dolphins and harbour porpoises. There were fewer delays due to other cetacean species and delays due to the presence of seals were uncommon. There was some evidence that delays were more likely at the beginning of a survey; since 2003 delays occurred for one of every 131 survey lines or airgun tests that were the first shots of the survey, but for only one of every 185 subsequent lines or tests (Stone 2015). The level of compliance with the requirement to delay firing was highly variable between years (Figure 3.14). As there were only a small number of delays, each occasion when the correct procedures were or were not implemented resulted in a substantial raising or lowering of the proportion where there was compliance for that year. Although highly variable, overall compliance with the requirement to delay firing if marine mammals are in close proximity has shown a general improvement over time (Figure 3.14), although the level of compliance with this aspect of the guidelines still lags behind that of pre-shooting searches and soft starts. Incorrect procedures in a delay situation were sometimes due to the subsequent soft start being too short (20% of all delay situations), but more often due to the delay not being long enough (27% of all delay situations).

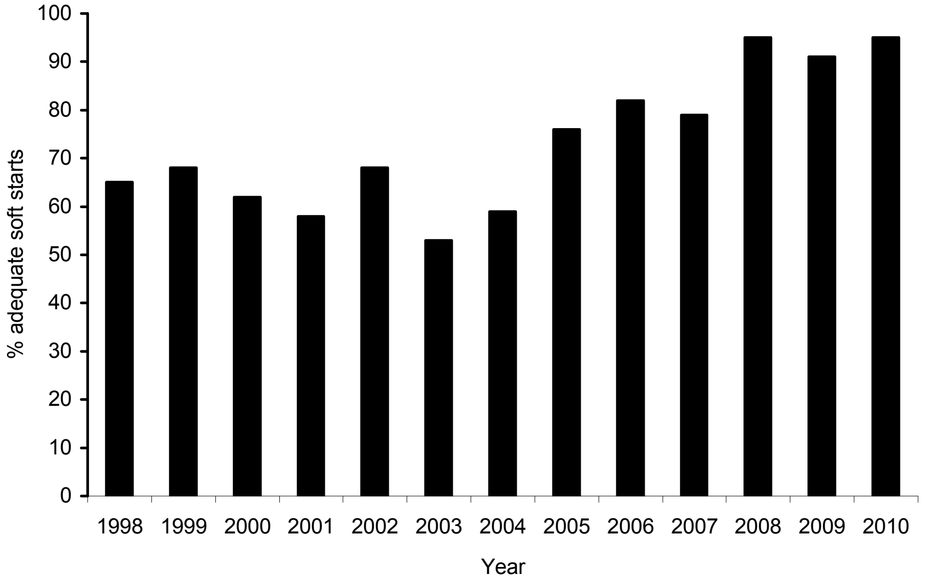

Figure 3.13. Proportion of adequate soft starts within the UKCS over time (all survey types).

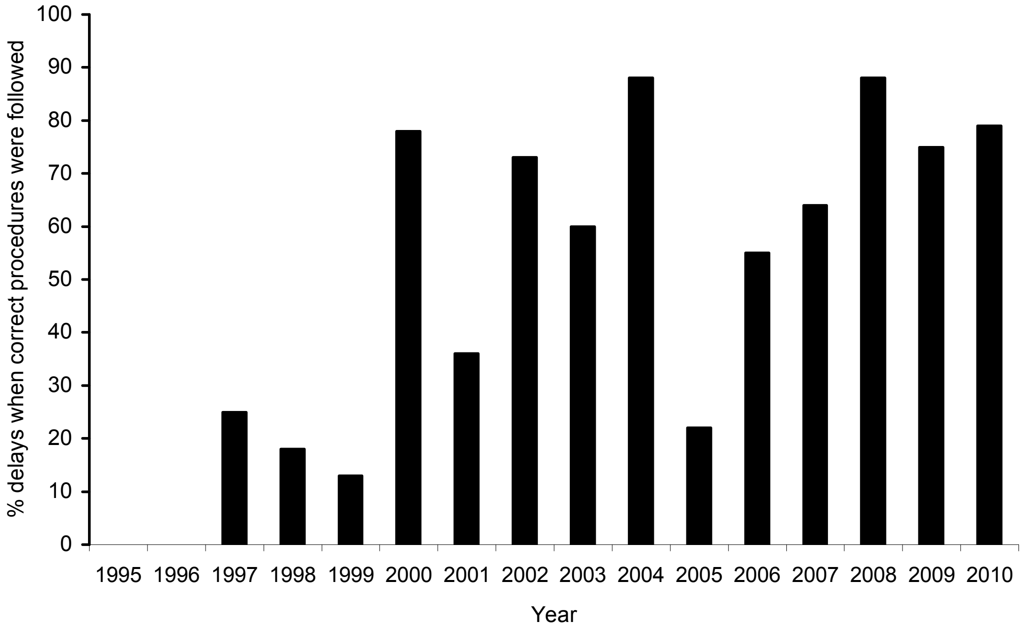

Figure 3.14. Proportion of occasions when correct procedures were followed when a delay in firing was required within the UKCS due to the presence of marine mammals (no delays were needed in 1995 or 1996).

4 Discussion

4.1 Distribution of marine mammals

The distribution of marine mammals observed from seismic survey vessels to a large extent reflects the distribution of survey effort. Any trends in distribution that may be apparent need to be treated with caution as a seismic survey vessel is not an unbiased platform and its operation may have an influence on the observed distribution and abundance. Allowing for uneven survey effort, the distribution of marine mammals observed largely agrees with previous knowledge, with high numbers of sightings in known areas of high abundance (e.g. deep waters to the west of Britain and Ireland) and low numbers in known areas of relatively low abundance (e.g. the southern North Sea).

The large whales (humpback, blue, fin, sei and sperm whales) were found mostly in shelf edge and deep waters to the north and west of Britain and Ireland, in agreement with known distribution (Clark and Charif 1998; Evans 1990; JNCC 1995; NERC 1998; Pollock *et al* 2000; Reid *et al* 2003; Skov *et al* 1995). A sighting of a humpback whale closer inshore to the east of Shetland is consistent with known records of sightings on the continental shelf, which Reid *et al* (2003) notes have come mainly from the Northern Isles. There was a sighting of a fin whale in the central North Sea, with Camphuysen and Winter (1995) having also noted occasional fin whale sightings in the North Sea. However, there was no obvious reason for the decrease in fin whale sightings to the west of Shetland in more recent years.

Sightings of beaked whales (northern bottlenose whale and Sowerby's beaked whale) occurred almost exclusively in shelf edge and deep waters. Beaked whales are known to occur mainly in deep waters (e.g. CODA 2009), although there have been some rare sightings of beaked whales, including Sowerby's beaked whale, in the Minch (Reid *et al* 2003). One northern bottlenose whale was seen off Aberdeen; occasional inshore sightings of this species have been reported previously (Weir 1999; Weir and Coles 1998).

Long-finned pilot whales were seen predominantly in shelf edge and deep waters to the north and west of Scotland, with some also to the west of Ireland and in the South-west Approaches, agreeing with their known distribution (Bloor *et al* 1996; CODA 2009; JNCC 1995; NERC 1998; Pollock *et al* 1997, 2000; Reid *et al* 2003; Skov *et al* 1995). Some were also seen along the western edge of the Rinne, with Reid *et al* (2003) also noting several sightings in this area. Killer whales were seen mainly in northern waters with a concentration to the north-east of Shetland, matching their preference for cooler waters (Evans 1992). There was one sighting of false killer whales to the west of Ireland in a similar location to a sighting reported previously (Reid *et al* 2003).

Minke whales were widely distributed, with many sightings throughout the central and northern North Sea and into deeper waters further north. Northridge *et al* (1995) and Reid *et al* (2003) found concentrations of minke whales close to land. Although some were seen relatively close inshore particularly around the coast of Scotland, most effort was further offshore so these inshore areas were less well surveyed. The SCANS and SCANS-II surveys found that a weak concentration of minke whales off southeast Scotland in 1994 had dissipated to the central North Sea in 2005 (Hammond *et al* 2013).

Atlantic white-sided dolphins, striped dolphins and Risso's dolphins were found mostly on the shelf edge and in deeper waters. For Atlantic white-sided dolphins and striped dolphins this is consistent with previous findings (Evans 1990, 1992; JNCC 1995; NERC 1998; Pollock *et al* 1997, 2000; Reid *et al* 2003; Skov *et al* 1995). However, Reid *et al* (2003) considered Risso's dolphins to be a continental shelf species and noted that although a few records were from immediately over the shelf break none were in deeper waters. More than half of the sightings of Risso's dolphins from seismic survey vessels were beyond the continental shelf with several sightings occurring in deep waters of more than 1,000m depth. Their distribution was also further north than reported by Reid *et al* (2003), although Bloch *et al* (2012) noted recent occurrences in Faroese waters and considered that there was a likely northward extension of the species' known range. Bottlenose dolphin distribution was also slightly different from that reported previously. Sightings occurred in St George's Channel and off the Aberdeenshire and Moray coasts, in areas of resident populations, although such sightings were relatively few as might be expected due to the low effort closer inshore. However, there were more sightings of bottlenose dolphins further offshore in the central and northern North Sea than were reported by Reid *et al* (2003), although offshore sightings along the shelf edge and deeper waters to the west of Britain agree with known distribution (CODA 2009; Hammond *et al* 2013; Reid *et al* 2003).

Both striped dolphins and short-beaked common dolphins in UK waters are found predominantly to the south-west (CODA 2009; NERC 1998; Reid *et al* 2003), although their range is predicted to expand progressively northwards as water temperatures increase over time (Lambert *et al* 2011; MacLeod 2009). Given the low effort from seismic survey vessels to the south-west of the UK this south-westerly skew was not evident, although a number of sightings of short-beaked common dolphins did occur in St George's Channel and the Celtic Sea. Short-beaked common dolphins were also recorded in the central and northern North Sea. A change in their range related to past changes in water temperature has been demonstrated (Lambert *et al* 2011) and there have been more northerly sightings of this species reported in recent years (Robinson *et al* 2010). The sightings of striped dolphins in the central and southern North Sea are very anomalous compared to their normal distribution to the south and west of the UK (Reid *et al* 2003).

The white-beaked dolphin was the most common identified species of marine mammal observed from seismic survey vessels operating in UK waters. Previous studies of the distribution of this species have found it to occur mostly on the continental shelf (Hammond *et al* 2013; Northridge *et al* 1995; Reid *et al* 2003). While this was also true for those seen from seismic survey vessels, more were seen beyond the shelf to the north of Scotland than have been reported previously (Reid *et al* 2003). MacLeod *et al* (2007) found that the most important variable related to white-beaked dolphin distribution was water depth, with a preference being shown for shallower waters. Although the majority of white-beaked dolphins seen from seismic survey vessels were also found in shallower waters, nevertheless notable numbers of sightings occurred in deeper waters beyond the shelf edge.

Harbour porpoises are more abundant in the North Sea and adjacent areas than white-beaked and/ or Atlantic white-sided dolphins (Hammond *et al* 2013; Reid *et al* 2003), but the latter two species were more commonly seen by MMOs during seismic surveys. The relatively low numbers of harbour porpoises seen are likely at least in part to be due to difficulties in detecting this species (particularly as sea state increases above sea state 2; Hammond *et al* 2013) and the inexperience of some observers in detecting this small marine mammal. However, it may also indicate avoidance by harbour porpoises of areas where seismic surveys are taking place (whether due to airgun noise or general vessel avoidance) and further investigation of possible reasons for the relative lack of harbour porpoise sightings is warranted. The SCANS and SCANS-II surveys showed that the total abundance of harbour porpoise in the North Sea and adjacent waters did not change significantly between 1994 and 2005 but the distribution did change, with densities lower in the north and higher in the south in 2005 than in 1994 (Hammond *et al* 2013). It was considered that a likely explanation for this change in distribution of harbour porpoises was a change in the distribution or availability of their prey (Hammond *et al* 2013). Of the harbour porpoises that were seen from seismic survey vessels, numbers of sightings increased in the southern North Sea from 2006 onwards and decreased further north (with the exception of the Outer Moray Firth), agreeing with the trend found by SCANS-II (Hammond *et al* 2013).

There were fewer sightings of harbour seals than grey seals but both species were seen at similar distances from haul-out sites such as the Moray Firth. Grey seals were thought to forage further from haul-out sites than harbour seals (Thompson *et al* 1996), but recent tagging studies have shown that harbour seals forage more extensively in offshore waters than was previously known (Sharples *et al* 2012).

4.2 Effects of seismic operations on marine mammals

The data collected by MMOs, including any monitoring to cover periods when the airguns are firing in addition to the required pre-shooting search, is valuable for investigating potential impacts of seismic operations on marine mammals. Injury to marine mammals as a result of acoustic input to the marine environment is a primary concern. Injuries to marine mammals are often not apparent unless the animal subsequently strands and even then it can be very difficult to establish the cause. Reports of possible injuries to marine mammals due to seismic surveying are very few. While there has been speculation that strandings of humpback whales in Brazil, Cuviers beaked whales in Mexico and illness/ injury of a pantropical spotted dolphin off Liberia may have been due to seismic surveying, these links were based on spatial and/ or temporal coincidence and remain inconclusive (Engel *et al* 2004; Gray and Van Waerebeek 2011; Taylor et al 2004). Observations from seismic survey vessels operating in UK waters showed no evidence of any injuries, but these would not necessarily be apparent from surface observations.

Under European and UK law, both deliberate injury and deliberate/ reckless disturbance of European protected species (EPS) are prohibited. 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 affect significantly their local distribution or abundance. Some behavioural responses to seismic operations were evident from the observations. Southall *et al* (2007) proposed a severity scale for ranking observed behavioural responses of free-ranging marine mammals to anthropogenic sound, ranging from no observable response (response score zero) to outright panic, flight, stampede, attack of conspecifics, stranding events or avoidance behaviour related to predator detection (all response score nine). The observed responses of marine mammals to seismic operations in UK waters can be considered in the context of these response scores. JNCC draft guidance on The Protection of Marine European Protected Species from Injury and Disturbance (JNCC *in litt*) proposes that a disturbance offence is more likely to occur when there is a risk of animals incurring sustained or chronic disruption of behaviour scoring five or more on Southall *et al*'s (2007) scale, or where there is a risk of animals being displaced from the area, with redistribution significantly different from natural variation.

Displacement of animals from an area, particularly feeding and/ or breeding areas, in response to anthropogenic activities could have significant impacts on individuals and populations, particularly if the displacement is prolonged. Long term avoidance of an area, beyond the duration of operations, is ranked highly on Southall *et al*'s (2007) severity scale of behavioural responses (response score eight) and such long-term avoidance could potentially impair the animals' ability to feed (thus affecting survival), to breed or to migrate etc. Data were not collected beyond the duration of seismic surveys to see whether any displacement persisted but lateral displacement during periods of airgun activity was observed for some species, as indicated by a reduction in the number of sightings or acoustic detections and/ or animals remaining further from the source at these times (sections 3.2.1 and 3.2.3). Where detection rates were reduced this suggests lateral displacement beyond the visual range of the observer, demonstrating at least minor avoidance of the sound source, which is ranked as response score six by Southall *et al*

(2007). However, there was no evidence that such avoidance was sustained as the higher detection rates when the airguns were not firing included many periods after the end of survey lines when shooting had only recently ceased. Nor was there any evidence that the displacement resulted in redistribution significantly different from natural variation. Species exhibiting lateral displacement beyond the visual range of the observer during periods of airgun activity on surveys with ‘large arrays’ included the minke whale, killer whale, white-beaked dolphin, Atlantic white-sided dolphin, harbour porpoise and grey seal, as well as all beaked whales combined (section 3.2.1).

During surveys with ‘small arrays’ only sperm whales and harbour porpoises gave any indication of lateral displacement beyond the visual range of the observer. Lucke *et al* (2009) found aversive behavioural responses of a single captive harbour porpoise when exposed to noise from a seismic airgun and also 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. Thompson *et al* (2013) found that seismic operations using a relatively small array (470 cu. in.) with similar sound exposure levels to those in Lucke *et al*’s (2009) study resulted in short-term avoidance of harbour porpoises, although animals were typically detected again at affected sites within a few hours and there were indications of possible habituation or tolerance as the survey progressed; those porpoises remaining in the area did however 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). An increased sensitivity compared to other species may explain why, in the present study, harbour porpoises were apparently displaced during periods of firing regardless of the size of the airgun array, while some other odontocetes appeared only to be displaced by larger airgun arrays.

Although only sperm whales and harbour porpoises showed evidence of lateral displacement beyond the visual range of the observer during periods of firing on surveys with ‘small arrays’, there was nevertheless a significant decrease in overall sighting rates of groups combining all delphinids and all small odontocetes after the first week of these surveys (section 3.2.2). With repeated exposure to sound increased habituation or increased sensitisation may occur (Richardson *et al* 1995), so it is possible that an initial tolerance of smaller airgun arrays by delphinids and small odontocetes might give way to increasing sensitisation as surveys progress; alternatively there could be some other explanation for the later decrease in sighting rates, such as a delayed reaction due to prey moving out of the area. The reduction in rates of delays after the initial use of airguns on a survey might point to an adaptive response, with animals ‘warned’ by previous firing perhaps being less likely to approach close to the vessel (section 3.4).

Where animals remained significantly further from the airguns during periods of airgun activity but detection rates were not reduced this may indicate lateral displacement of a lesser degree, i.e. not beyond the visual range of the observer. Bottlenose dolphins responded in this way when ‘large arrays’ were active (section 3.2.3). More localised responses were also indicated in some species during periods of airgun activity by an increased tendency to avoid or travel away from the vessel and/ or a reduction in positive interactions with (e.g. bow-riding) or travel towards the vessel or its equipment (section 3.2.4). This more localised avoidance may indicate a level of disturbance or discomfort and was evident on surveys with ‘large arrays’ for fin whales and long-finned pilot whales, even though there was no significant lateral displacement of these species. On surveys with ‘small arrays’, localised avoidance without significant lateral displacement was indicated for groups comprising all cetaceans combined, all delphinids combined, all small odontocetes combined and *Lagenorhynchus* spp. Minor avoidance of the sound source, ranked as response score six on the severity scale of Southall *et al* (2007), could potentially have an impact on activities such as foraging, although again there is no evidence that such responses were sustained.

Where there is no avoidance of the sound source, Southall *et al* (2007) rank changes in locomotion speed, direction and/ or dive profiles as response scores three, four or five, depending on whether they are minor, moderate or extensive/ prolonged. On surveys with 'large arrays', short-beaked common dolphins showed an increase in swimming speed when the airguns were active but no behaviours that would indicate avoidance of the airgun noise (section 3.2.4). Gailey *et al* (2007) also found increased swimming speeds of cetaceans in response to airgun activity.

A reduction in foraging effort may clearly have significant consequences for individuals and populations. Although feeding may not always be apparent from surface observations, when all cetaceans were combined significantly fewer animals were recorded as feeding when 'large arrays' were active (section 3.2.4). Jochens *et al* (2008) and Miller *et al* (2009) found no horizontal avoidance of seismic operations by sperm whales but did find that there may be a decrease in foraging effort (indicated by changes in sperm whale buzz rates associated with foraging); as this species forages at depth, a reduction in foraging would not be readily apparent from the data collected by MMOs. It should be noted that although there were no observed effects of noise from 'large arrays' on species such as sperm whales, there could potentially be effects that were not observed; behavioural observations were limited to periods when animals were at the surface (representing a relatively small proportion of time for deep divers such as sperm whales). It should also be noted that some responses of marine mammals to noise could be subtle and not able to be observed by MMOs (e.g. increased stress hormones; Rolland *et al* 2012; Romano *et al* 2004).

When 'large arrays' were active there were some indications that some cetaceans may remain closer to the surface (surfacing frequently, logging, apparently resting or milling), where noise levels may be lower due to the Lloyd's mirror effect (Richardson *et al* 1995; Urick 1983), although this was not a universal response (section 3.2.4). Robertson *et al* (2013) found that bowhead whales spent less time at the surface and Gailey *et al* (2007) found that gray whales stayed underwater longer in response to seismic operations, but most other studies have indicated that cetaceans may remain near the surface in response to noise. For example, McCauley *et al* (1998, 2000) found that humpback whales spent more time at the surface during periods of seismic operations and 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. Also, Barkaszi *et al* (2012) found that sperm whales in the Gulf of Mexico were surfacing more when airguns were at full power than when they were silent. Robertson *et al* (2013) suggested that changes in surfacing, respiration and dive behaviours of cetaceans exposed to seismic operations may have implications for the ability to detect animals. If cetaceans remain near the surface at times of airgun activity this could make them easier to detect visually and might lead to a relative increase in sighting rates at these times. As most of the effort in the present study was visual, any behaviours which may have influenced visual detection rates could have the potential to mask any changes in numbers of animals in the vicinity. Therefore a lack of any significant difference in detection rates for some species in the present study does not necessarily rule out overall avoidance by these species. Robertson *et al* (2013) found that changes in surfacing, respiration and dive behaviours 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. The response of marine mammals to airgun activity is likely to be very complex, involving many variables that may contribute to results such as those for sperm whales in the present study, which are difficult to explain (i.e. detection rates of sperm whales were reduced during periods when 'small arrays' were active, suggesting that they moved out of the area, but when 'large arrays' were active no response was observed; section 3.2.1).

All UK MMO data were examined from 1994 (just prior to the introduction of the JNCC guidelines) until the end of 2010. Some subsets of this dataset have been analysed previously (Stone 1997, 1998, 2000, 2001, 2003a, b, 2006; Stone and Tasker 2006), but these previous studies used data pooled over a maximum of four years. Pooling all data from 1994 to 2010 provided a much larger dataset, thereby resulting in larger sample sizes which permitted statistical testing of a greater range of responses over a greater range of species than was possible previously, although there were still some aspects of the analysis where sample sizes were low and species needed to be combined. For the first time beaked whales were able to be included in the analysis, although sample sizes were low and all species of beaked whale had to be combined. Nevertheless it was possible to demonstrate that detection rates of beaked whales were significantly lower when 'large arrays' were active (section 3.2.1), whereas previously there has been little evidence that beaked whales respond overtly to the noise from seismic airguns (Moulton and Holst 2010). One seismic survey has been implicated in the stranding of Cuviers beaked whales but without conclusive evidence of a link (Taylor *et al* 2004). Beaked whales are known to be sensitive to other anthropogenic noise, with cases of mass strandings related to the use of military mid-range frequency sonar (Balcomb and Claridge 2001; Cox *et al* 2006; Evans and England 2001; Fernández *et al* 2005; Tyack *et al* 2011). Southall *et al* (2007) suggested that regulatory agencies should consider adopting provisional injury criteria for beaked whales exposed to military sonar at lower levels than for other mid frequency cetaceans. Seismic airguns use predominantly low frequencies up to around 200Hz (Gausland 2001; Gulland and Walker 2001) whereas mid-range frequency sonar uses frequencies of around 3-8kHz (Evans and England 2001; Tyack *et al* 2011), so the results are not necessarily directly comparable, but nevertheless a response of beaked whales to seismic airguns has been noted here.

Responses of bottlenose dolphins also were not able to be tested previously but the larger dataset showed localised avoidance, increased swimming speed and increased incidence of breaching when 'large arrays' were active (sections 3.2.3 and 3.2.4). Furthermore, grey seals were found to have significantly lower detection rates when 'large arrays' were active (section 3.2.1), whereas previously sample sizes were too low to examine responses of seals. Harris *et al* (2001) showed some lateral displacement of seals (mostly ringed seals) during seismic surveys. However, some other species that previously could not be examined due to low sample sizes were found to show no discernible effects (humpback whale, sei whale, Risso's dolphin and harbour seal).

Baleen whales are estimated to have functional hearing within the range 7Hz to 22kHz, while most odontocetes belong to a mid-frequency hearing group with functional hearing from about 150Hz to 160kHz and porpoises belong to a high frequency hearing group with functional hearing between 200Hz and 180kHz (Southall *et al* 2007). As many anthropogenic sound sources are of low frequency it has often been assumed that baleen whales would be more vulnerable to disturbance from such sources than odontocetes. Seismic airguns, for example, produce peak energy at low frequencies up to about 200Hz (Gausland 2001; Gulland and Walker 2001). These low frequency sounds can travel long distances; for example, Nieukirk *et al* (2012) recorded airgun sounds in some cases almost 4,000km away from the source and Hildebrand (2009) noted that seismic sources contributed to low frequency ambient noise across ocean basins. Although avoidance of seismic survey vessels has been demonstrated for baleen whales such as bowhead whales, gray whales and humpback whales elsewhere (e.g. Ljungblad *et al* 1988; McCauley *et al* 1998, 2000; Moulton and Holst 2010; Richardson and Greene 1993; Richardson *et al* 1986, 1999; Yazvenko *et al* 2007), previously no effects were observed on individual baleen whale species in UK waters (Stone and Tasker 2006). However, use of the larger dataset revealed lateral displacement of minke whales (indicated by lower detection rates) when 'large arrays' were active and localised avoidance by fin whales at these times (no change in detection rates but fin whales tended to avoid or travel away from the vessel) (sections 3.2.1 and

3.2.4). It has been noted that impacts of human pressures on the minke whale are largely unknown (Thomsen *et al* 2011); localised avoidance of active airguns by minke whales has been observed in the northwest Atlantic (Moulton and Holst 2010) and the present study has confirmed that minke whales in UK waters show similar avoidance of seismic operations. Fin whales in the Mediterranean Sea modified their vocalisations and moved out of the area of a seismic survey for an extended period (Castellote *et al* 2012); although such displacement was not observed in fin whales in UK waters nevertheless some localised avoidance was found. In the present study no responses were observed in either humpback whales or sei whales, although sample sizes were low. Elsewhere responses to seismic survey vessels have been demonstrated for humpback whales (Cerchio *et al* 2014; McCauley *et al* 1998, 2000; Moulton and Holst 2010).

Odontocetes hear best at frequencies mostly above those at which the peak energy from seismic airguns is produced. Nevertheless, several species of mid frequency odontocete in UK waters (beaked whales, long-finned pilot whales, killer whales, bottlenose dolphin, white-beaked dolphin and Atlantic white-sided dolphin) demonstrated some degree of avoidance (sections 3.2.1 to 3.2.4), or in the absence of avoidance a change in swimming behaviour (short-beaked common dolphin; section 3.2.4). Harbour porpoises, in the high frequency group, also demonstrated avoidance (section 3.2.1). Although sound from seismic airguns is predominantly low frequency, nevertheless higher frequency sounds are also emitted that would be audible to odontocetes (De Ruiter *et al* 2006; Goold and Fish 1998; Madsen *et al* 2006; Potter *et al* 2007), although these high frequency sounds are likely to attenuate rapidly (Potter *et al* 2007). It seems that in UK waters, the tendency of cetacean groups to show a response to noise from seismic airguns does not correlate directly with what might be expected based on their hearing abilities. It could be that the responses are driven not only by the ability to hear the sound but also by how the sound is perceived; for example, animals may avoid sounds that they might interpret as indicating the presence of predators, to which smaller species may be more vulnerable. Similar responses of small odontocetes to noise from seismic airguns have been observed elsewhere; for example, Barkaszi *et al* (2012) examined MMO data from the Gulf of Mexico and demonstrated that delphinids showed spatial avoidance, displayed more surface behaviours such as breaching and porpoising and were less likely to display bow-riding behaviour during periods of airgun activity. Weir (2008a) found that Atlantic spotted dolphins showed a more marked overt response to airgun sound than either humpback whales or sperm whales.

The larger dataset also allowed greater examination of the response of marine mammals to the soft start in UK waters than has been possible previously (Stone 2006; Stone and Tasker 2006). Whether the soft start is an effective mitigation measure has been identified as a key question of interest and the recording forms in the UK were revised in 2009 to allow a distinction between effort during the soft start and at full power to aid in addressing this question (Barton *et al* 2008). The results showed that all species or species groups tested had reduced detection rates during the soft start compared to when the airguns were not firing (section 3.3). All species groups tested also showed an increased tendency to avoid or travel away from the vessel during soft starts of 'large arrays' (section 3.3), although not all individuals displayed such behaviours. These observed responses suggest that the soft start can be a useful mitigation tool, causing some marine mammals to move away from the immediate vicinity of airguns before full power is reached, thereby helping to avoid exposure to high levels of sound. Movement directed away from the source can only reduce exposure levels if the avoidance speed of the animal is much greater than the approach speed of the source (Von Benda-Beckmann *et al* 2014); seismic survey vessels towing airguns typically travel at relatively low speeds (around 4-5 knots), therefore movement away from the source may be effective at reducing exposure to sound from seismic operations. However, the lack of a universal response during the soft start procedure highlights the need to monitor for marine mammals prior to commencing firing airguns, with subsequent delay of firing if marine mammals are detected within the mitigation zone. For undetected animals, the soft start may also offer protection to some individuals by causing them to move out of the vicinity of the airguns before full power is reached.

Although the results here showed a high level of agreement in the response to the soft start between the species and species groups tested, the testing of individual species was limited to minke whales, white-beaked dolphins and Atlantic white-sided dolphins due to data availability. Therefore a degree of caution should be exercised as other species may respond differently. Nothing is known, for example, about the effectiveness of the soft start for sensitive species such as beaked whales (Barlow and Gisiner 2006). Moulton and Holst (2010) suggested that the effectiveness of the soft start varies with species and probably circumstances; in the north-west Atlantic they found mysticetes were observed further from the survey vessel during the soft start than when the airguns were silent but, in contrast to the present study, found no response in delphinids or toothed whales and considered that the soft start may be largely ineffective for some odontocetes. Weir (2008b) gave a detailed report on the response of a single pod of short-finned pilot whales to a soft start and although the whales showed an initial avoidance response this was limited in space and time, with the directed movement away from the source changing to milling at the surface, although it was noted that this might represent vertical avoidance. This, however, contrasts with the observation here that cetaceans were more likely to dive if the soft start commenced during the encounter (section 3.3). This observation was perhaps surprising, as sound levels may be lower at or near the surface due to interference between direct and surface-reflected sound (Richardson *et al* 1995; Urick 1983), so animals might be expected to be more likely to remain near the surface at the onset of noise.

There is clearly a need for more detailed studies on the response of marine mammals to the soft start procedure. Noise modelling can be used to investigate the effectiveness of the soft start, but needs to be set in the context of the animals' response. Von Benda-Beckmann *et al* (2014) used modelling to demonstrate that the effectiveness of soft start for sonar depended strongly on the assumed response threshold of animals and differed with soft start duration. Modelling has also indicated that the threshold levels for hearing injury for cetaceans are not reached during the initial stages of a soft start of an airgun array, although threshold criteria for pinnipeds may be approached, perhaps requiring additional mitigation for seismic surveys operating close to haul-out areas for pinnipeds (Hannay *et al* 2011). Von Benda-Beckmann *et al* (2014) noted that critical research questions that need addressing are documentation of avoidance strategies (horizontal/ vertical avoidance, swim speeds), behavioural context and estimates of sound dosage that predicts the onset of an avoidance response for sounds other than sonar.

4.3 Compliance with the JNCC guidelines

Only overall trends in compliance with the key aspects of the JNCC guidelines were considered here (for more detail on individual years see Stone 1998, 2000, 2001, 2003a, 2006, 2015), but the general picture was one of improvement over time. Pre-shooting searches were mostly of acceptable duration, but the pre-shooting search is only effective as a mitigation tool if a delay is properly implemented for any marine mammals that are detected in the mitigation zone during the pre-shooting search. Therefore, assessment of the pre-shooting search on its own should not be taken as a measure of how well the guidelines are being implemented. Compliance with the requirement to delay the commencement of firing if marine mammals are detected in the mitigation zone has shown a general improvement over time, but is highly variable and lags behind other aspects of compliance with the guidelines. Further improvement in compliance with the requirement to delay firing would increase the overall effectiveness of the pre-shooting search as a mitigation tool.

The results here have indicated that the soft start may be a useful mitigation tool, causing some marine mammals to move away from the vicinity of the airguns before full power is reached, but it will only be effective if animals have sufficient time during the soft start to move to a distance where exposure to high levels of sound would be avoided. It is therefore important that there is compliance with the specified minimum duration for the soft start. The introduction in 2004 of alternative methods of performing a soft start for site surveys and VSP operations has clearly been a successful addition to the guidelines, resulting in an improvement in the proportion of soft starts meeting the specified minimum duration.

5 Conclusions

Based on observations in UK waters over a 16 year period, some responses of marine mammals to seismic surveys were evident. These responses did not correlate directly with what might be expected based on their hearing abilities, as small and medium-sized odontocetes showed responses as well as some baleen whales. On surveys with 'large arrays' (500 cu. in. or more) all small or medium-sized odontocete species (except Risso's dolphin) showed some significant response when airguns were active, whether this was lateral displacement or more localised avoidance or a change in behaviour. This included the first indication of a response by beaked whales to airgun activity in UK waters, where lateral displacement was indicated when 'large arrays' were active. Baleen whales, based on their hearing abilities, may be expected to show greater responses to seismic operations; minke whales showed lateral displacement in response to active 'large arrays', while fin whales showed more localised avoidance.

Responses of marine mammals were less evident on surveys with 'small arrays' (less than 500 cu. in.). The only individual species where lateral displacement was evident were the sperm whale and the harbour porpoise, although testing of responses for many species was limited by lower sample sizes. Baleen whales did not show any negative behavioural responses to surveys with 'small arrays'. Although responses were generally fewer than with 'large arrays', nevertheless the variation in effects observed confirm that mitigation measures should continue to apply to all types of seismic surveys and cover the risk to all marine mammal species.

The results presented here indicate that the soft start may be an effective mitigation measure, suggesting that some marine mammals were moving away from the airguns before full power was reached. However, information was only available for a few species, so there is still a need for further studies on the effectiveness of the soft start.

There has been an increase in the standard of soft starts in UK waters over the years. In recent years most soft starts lasted at least 20 minutes from the time of commencement until full power was reached. A visual pre-shooting search generally provided adequate monitoring during daylight hours, with delays in firing due to the presence of marine mammals in the mitigation zone being relatively rare. Although compliance with the requirement to delay showed a general improvement over time, there were still a number of occasions when delays were not correctly implemented and standards were lower than for compliance with other aspects of the JNCC guidelines.

It is acknowledged that MMO observations of cetacean behaviour have the potential to be biased given the difficulty in observing cetaceans, the subjective nature of interpreting behaviour and the possibility that the MMO may have an expectation, even if subconsciously, that animals will respond differentially between when seismic airguns are firing and when they are not firing. However, blind field trials cannot be achieved on board seismic surveys and experimental set ups (e.g. Cato *et al* 2013) would not be feasible over the same spatial and temporal scales and range of species as can be provided by MMO data. MMO data thus provide a valuable resource for investigating the potential impacts of industrial activities on marine mammals across a range of species and geographical areas. This report represents one of the longest term analyses of MMO data to date; every attempt has been made to limit bias potential where possible, for example by using matched pairs in the statistical analyses. There is a need to continue to collect MMO data to test the effectiveness of the guidelines and compliance therewith. Such studies should aim to improve mutual understanding between regulators/ advisors and industry in order that mitigation is applied correctly, is logistically feasible, is well justified and is proportional to the risk to species.

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Appendix 1

On all maps the short dashed line = 200m isobath; the long dashed line = 1,000m isobath.

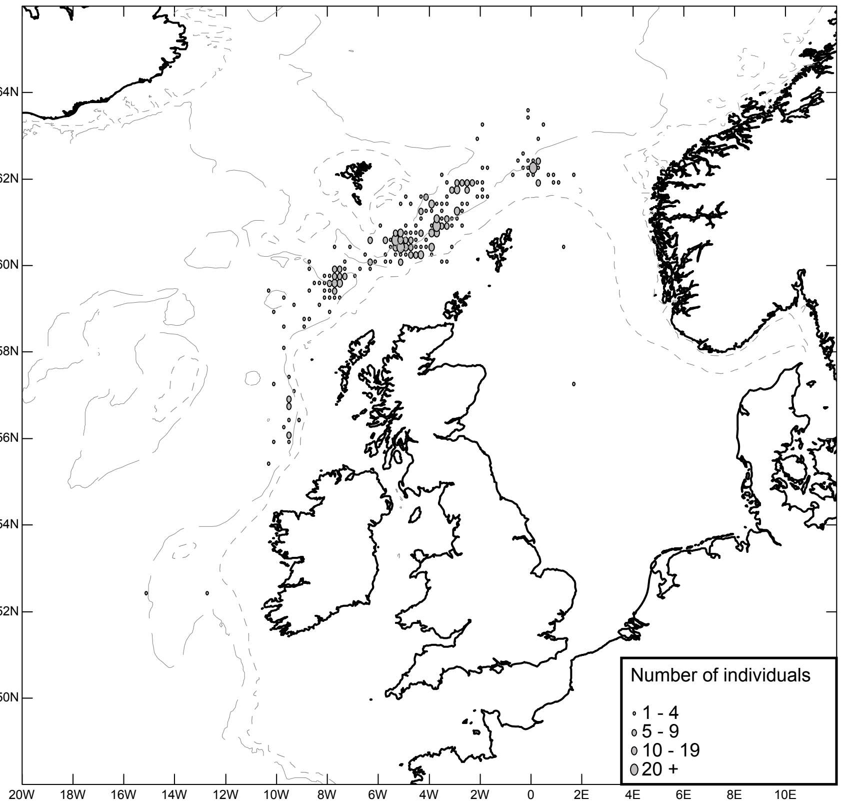

Figure 8.1. Fin whales encountered during seismic surveys, 1994-2010.

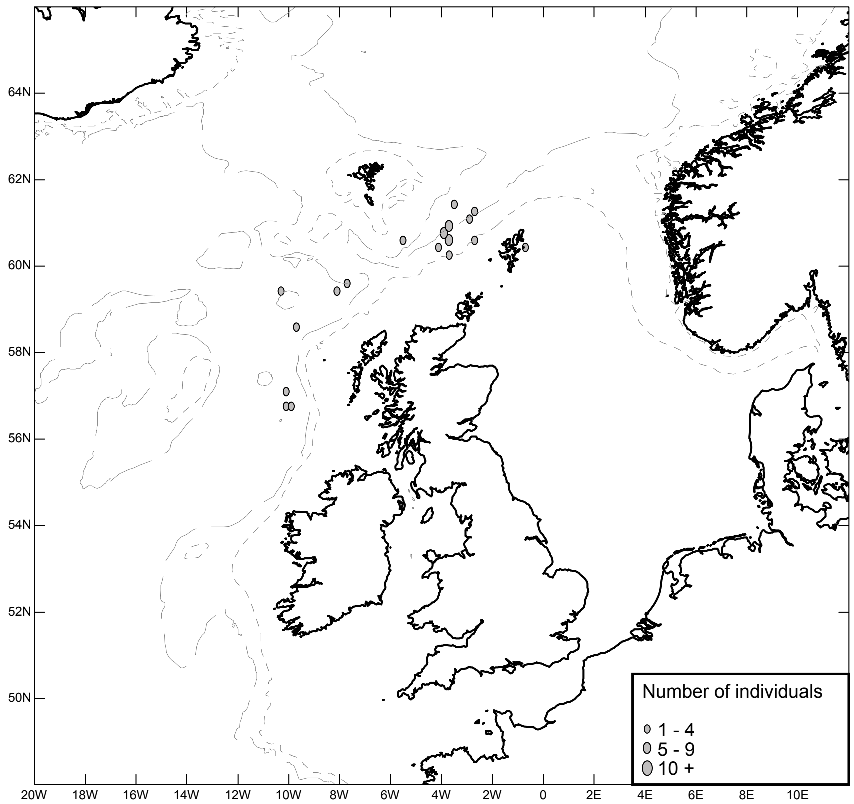

Figure 8.2. Humpback whales encountered during seismic surveys, 1994-2010.

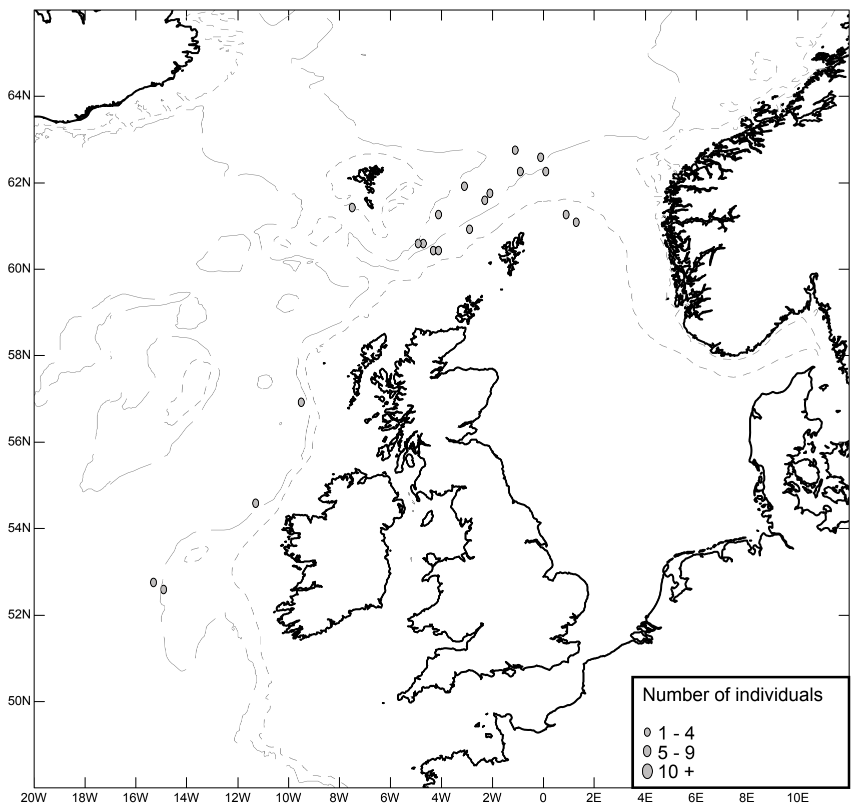

Figure 8.3. Sei whales encountered during seismic surveys, 1994-2010.

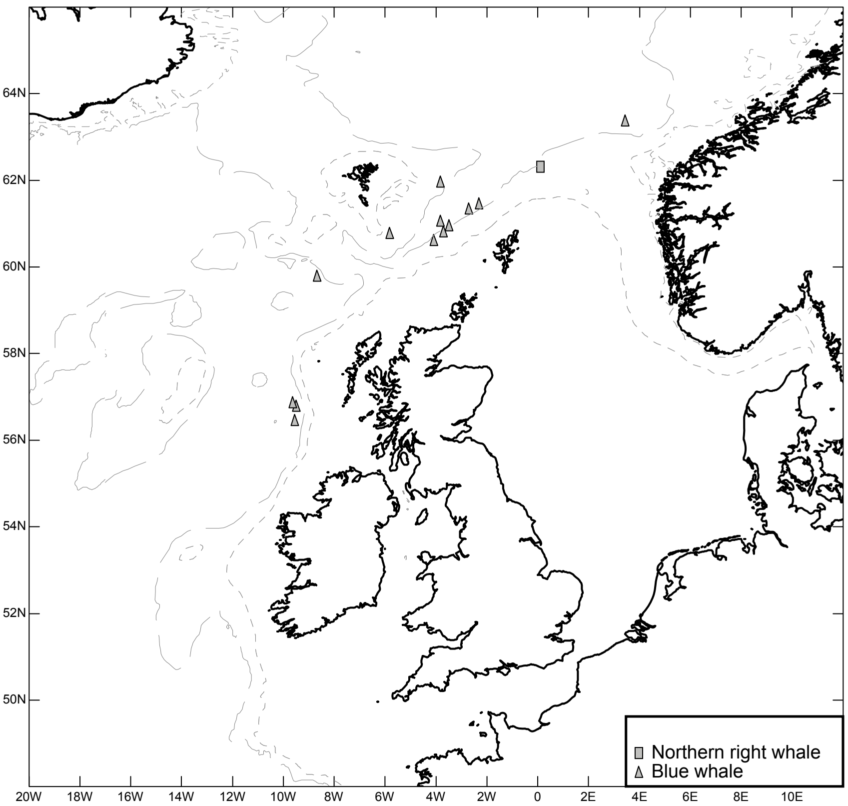

Figure 8.4. Northern right whale (probable) and blue whales encountered during seismic surveys, 1994-2010.

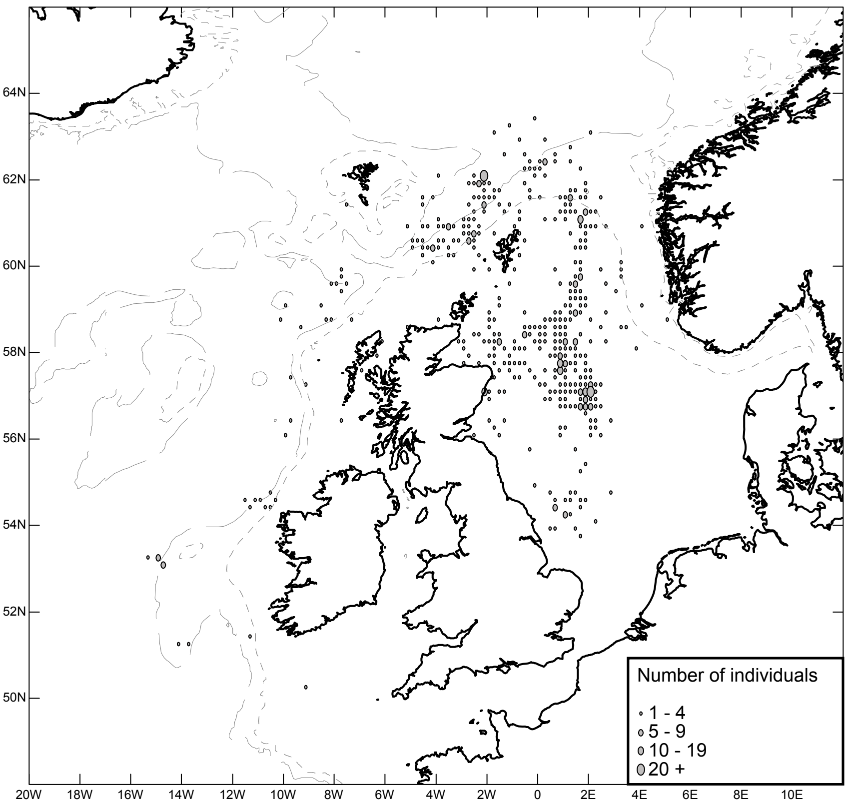

Figure 8.5. Minke whales encountered during seismic surveys, 1994-2010.

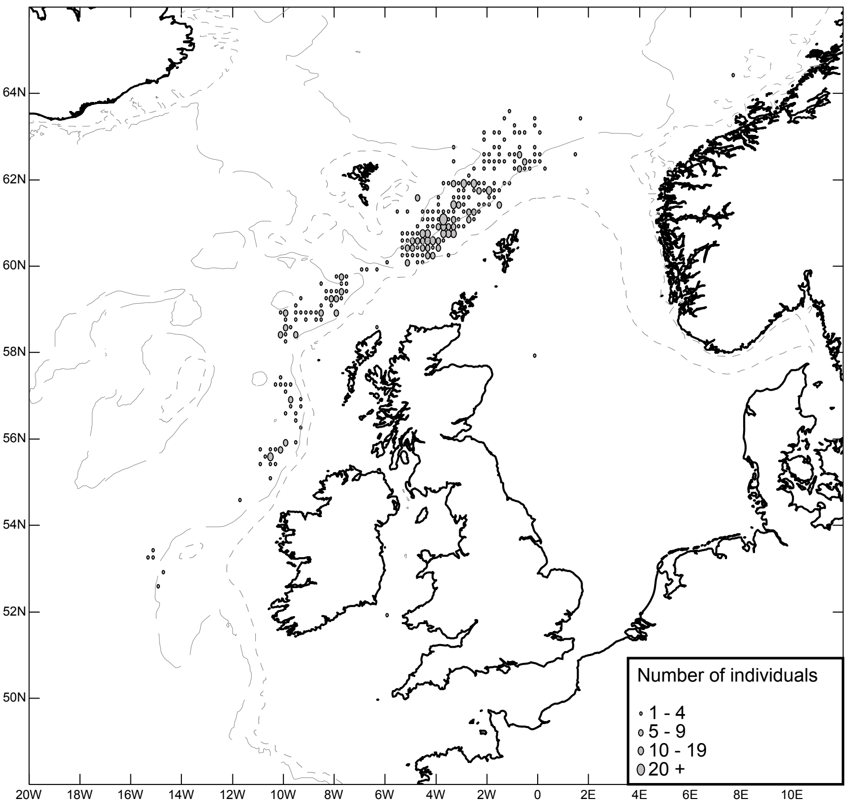

Figure 8.6. Sperm whales encountered during seismic surveys, 1994-2010.

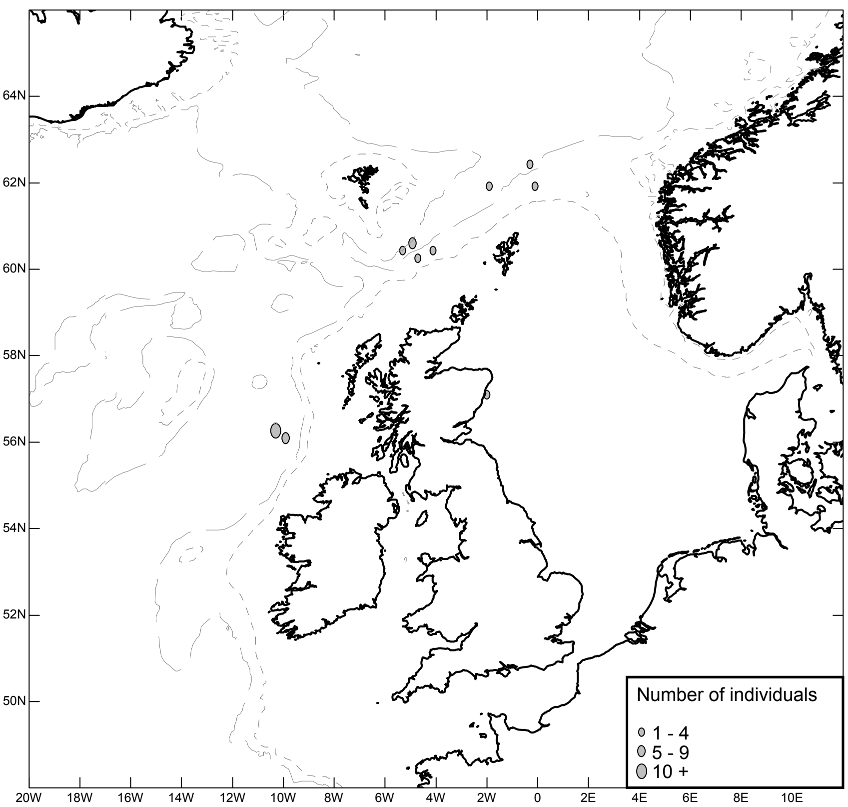

Figure 8.7. Northern bottlenose whales encountered during seismic surveys, 1994-2010.

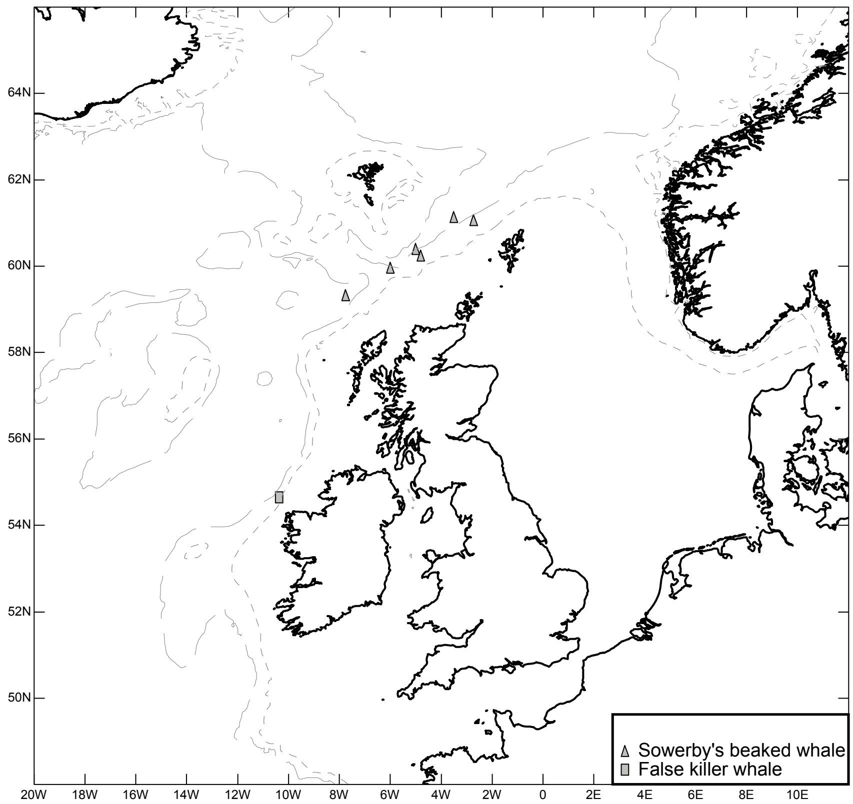

Figure 8.8. Sowerby's beaked whales and false killer whales encountered during seismic surveys, 1994-2010.

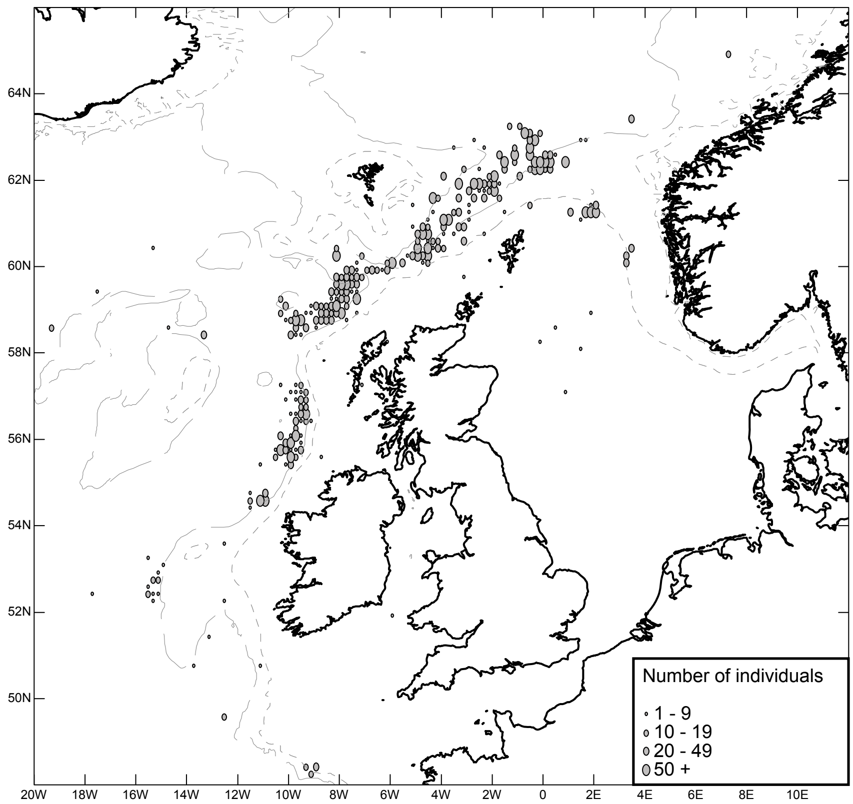

Figure 8.9. Long-finned pilot whales encountered during seismic surveys, 1994-2010.

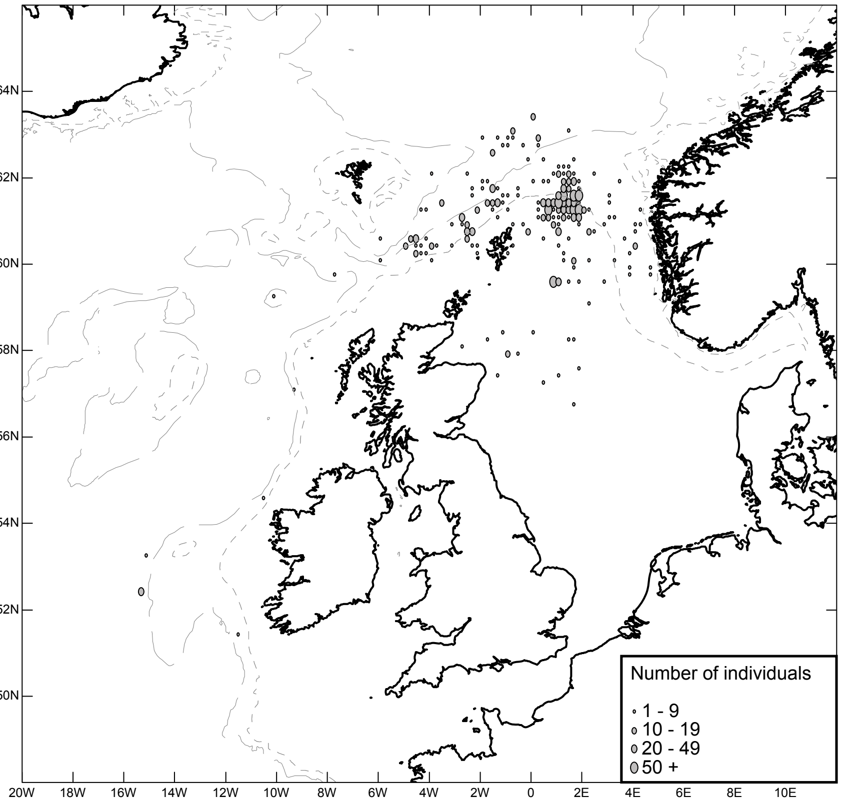

Figure 8.10. Killer whales encountered during seismic surveys, 1994-2010.

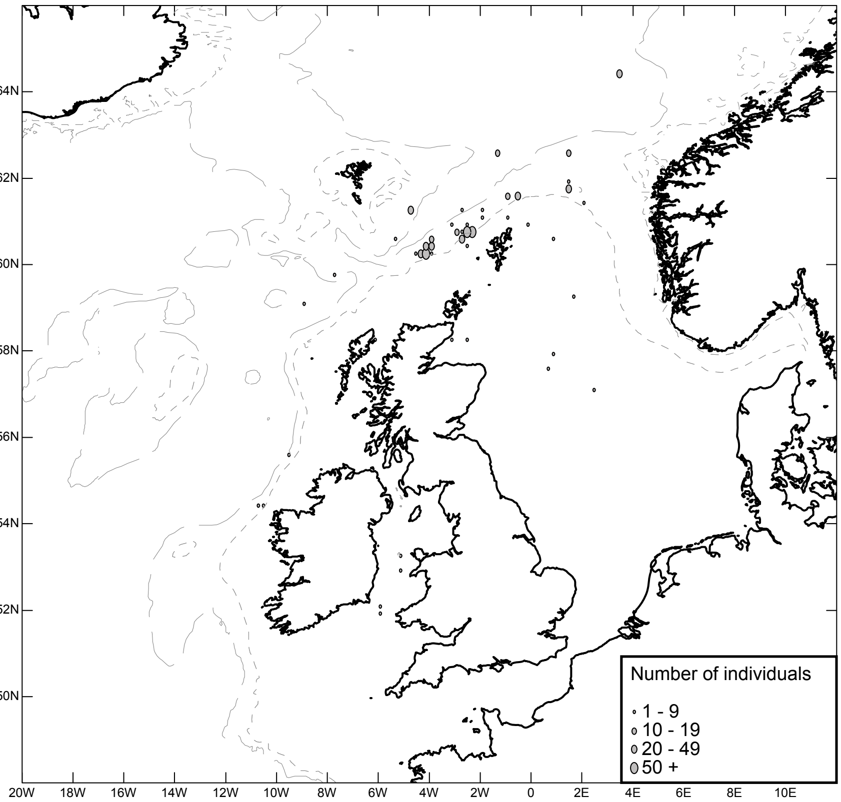

Figure 8.11. Risso's dolphins encountered during seismic surveys, 1994-2010.

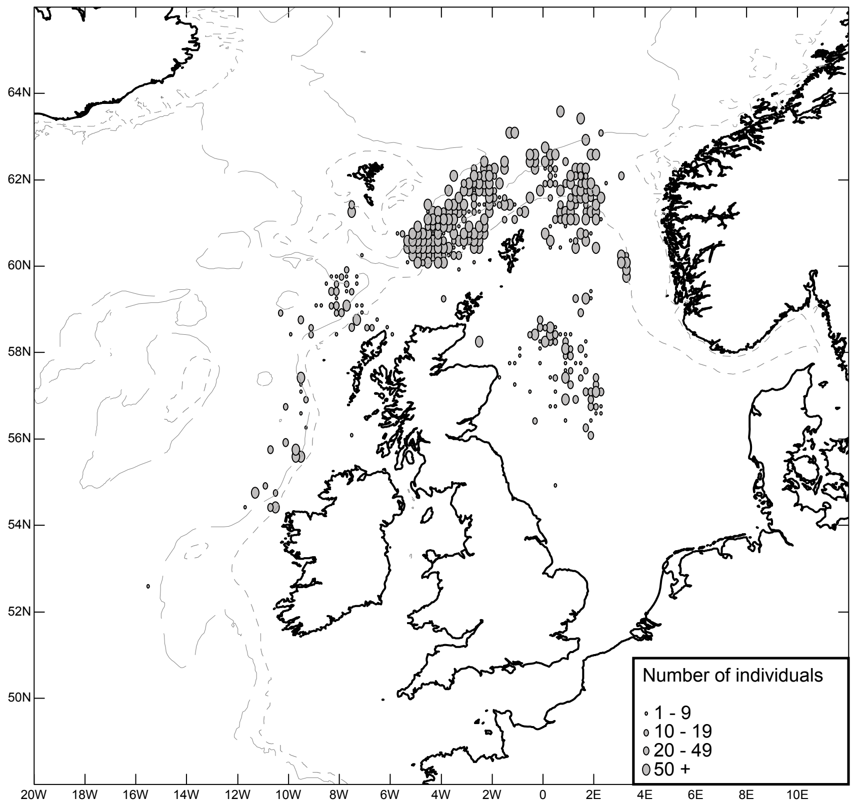

Figure 8.12. Atlantic white-sided dolphins encountered during seismic surveys, 1994-2010.

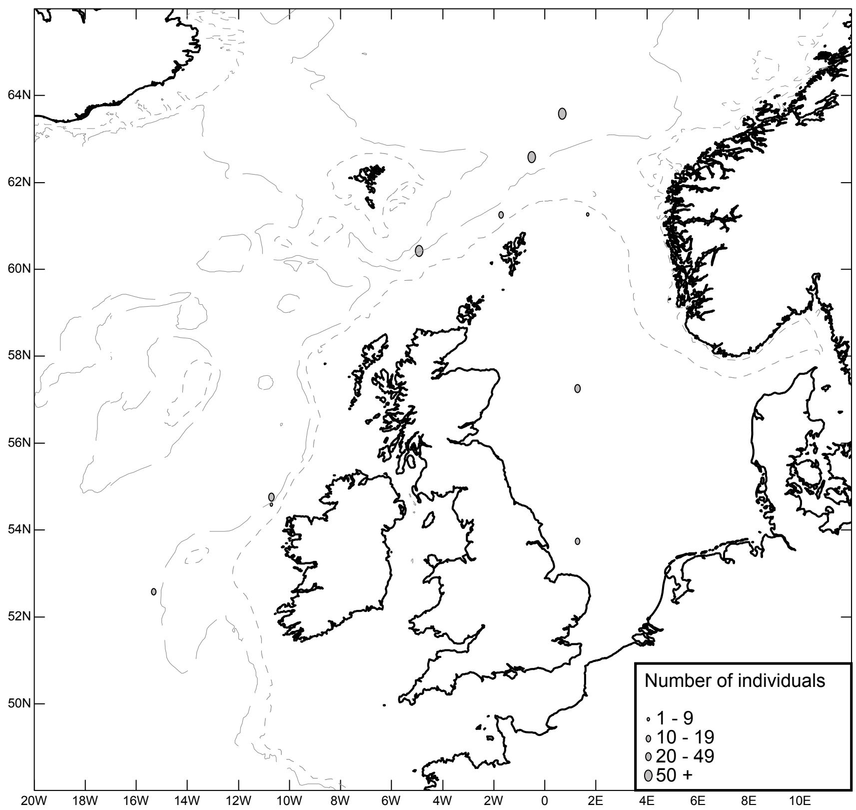

Figure 8.13. Striped dolphins encountered during seismic surveys, 1994-2010.

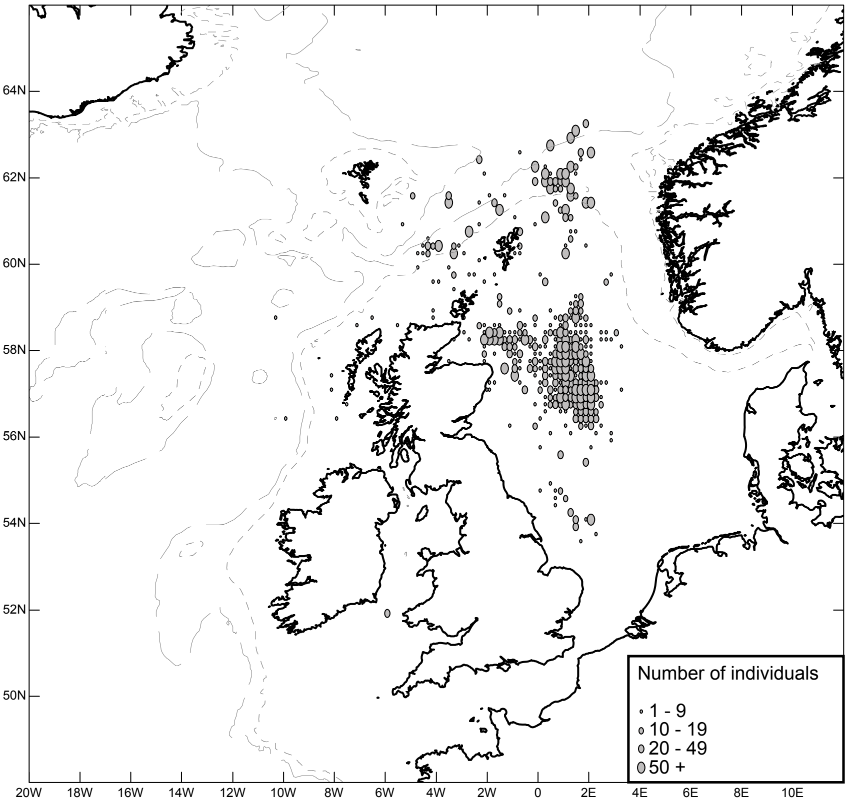

Figure 8.14. White-beaked dolphins encountered during seismic surveys, 1994-2010.

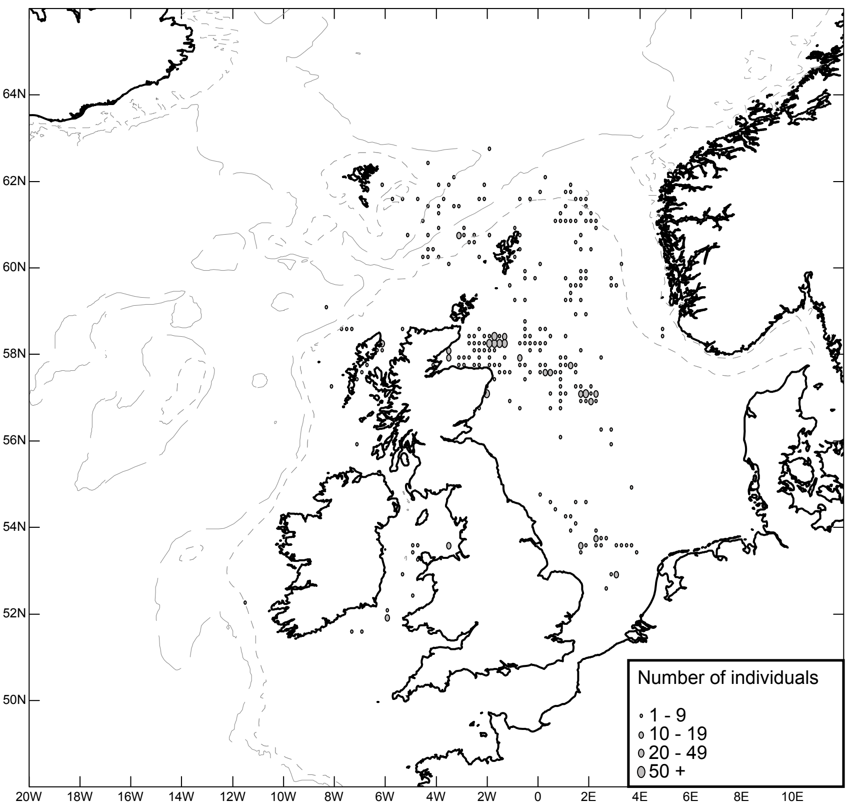

Figure 8.15. Harbour porpoises encountered during seismic surveys, 1994-2010.

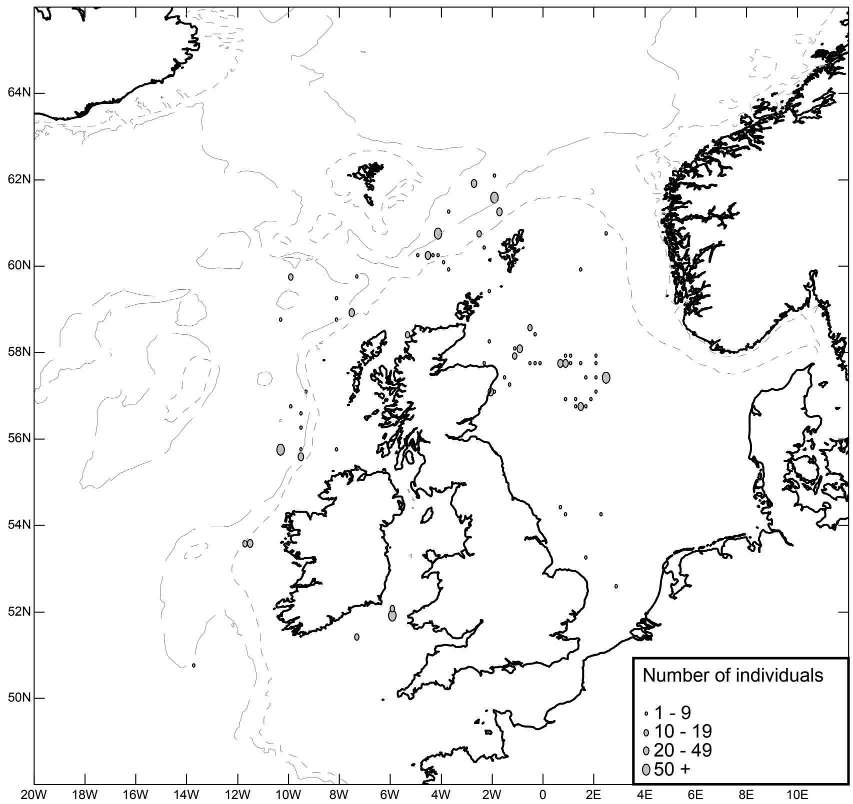

Figure 8.16. Bottlenose dolphins encountered during seismic surveys, 1994-2010.

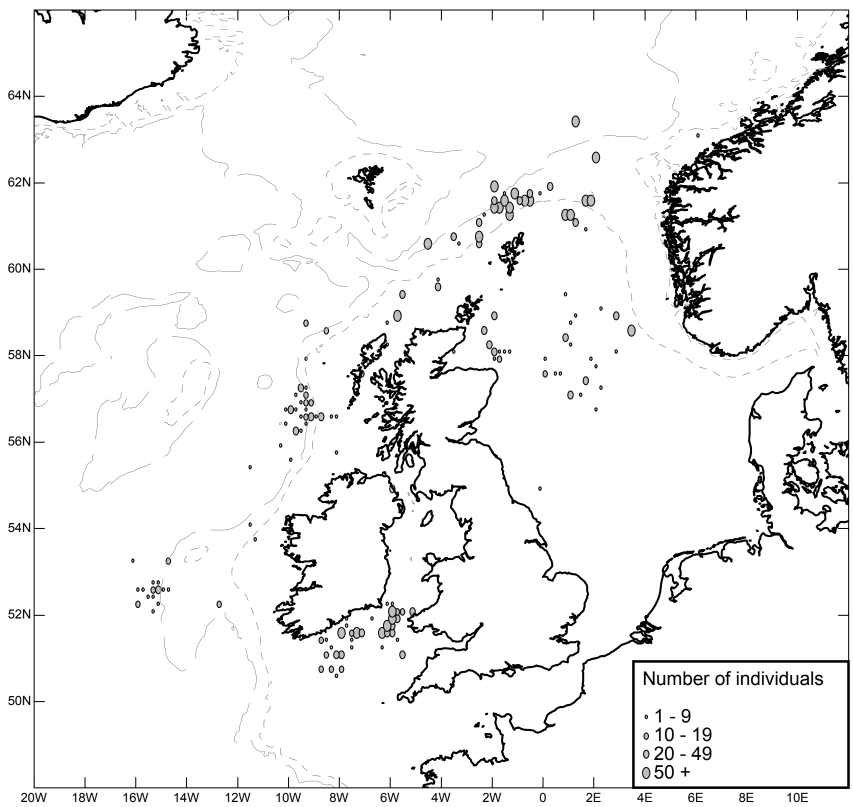

Figure 8.17. Short-beaked common dolphins encountered during seismic surveys, 1994-2010.

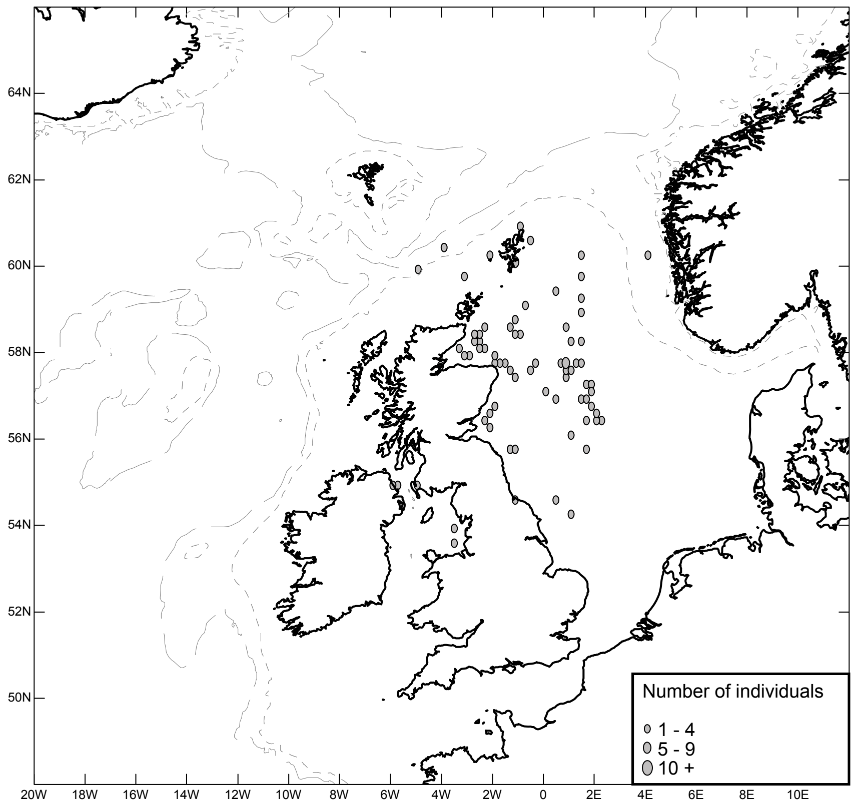

Figure 8.18. Grey seals encountered during seismic surveys, 1994-2010.

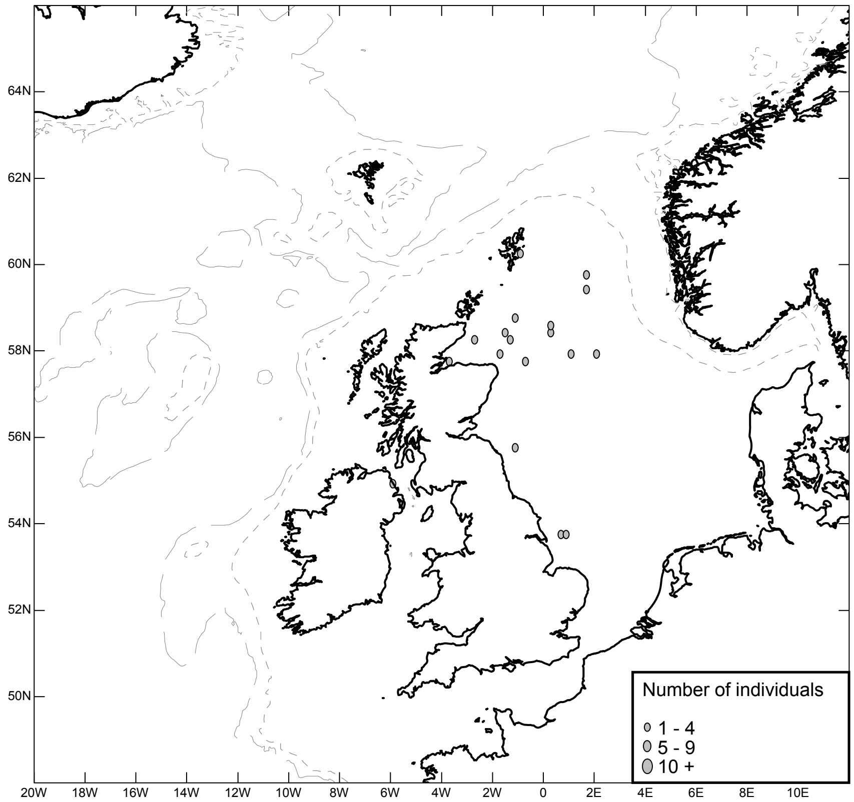

Figure 8.19. Harbour seals encountered during seismic surveys, 1994-2010.

Appendix 2

Scientific names of species mentioned in the text:

Harbour seal	*Phoca vitulina*
Grey seal	*Halichoerus grypus*
Ringed seal	*Pusa hispida*
Bowhead whale	*Balaena mysticetus*
Northern right whale	*Eubalaena glacialis*
Gray whale	*Eschrichtius robustus*
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*
Cuvier's beaked whale	*Ziphius cavirostris*
Short-finned pilot whale	*Globicephala macrorhynchus*
Long-finned pilot whale	*Globicephala melas*
Killer whale	*Orcinus orca*
False killer whale	*Pseudorca crassidens*
Risso's dolphin	*Grampus griseus*
Bottlenose dolphin	*Tursiops truncatus*
White-beaked dolphin	*Lagenorhynchus albirostris*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Short-beaked common dolphin	*Delphinus delphis*
Striped dolphin	*Stenella coeruleoalba*
Pantropical spotted dolphin	*Stenella attenuata*
Atlantic spotted dolphin	*Stenella frontalis*
Harbour porpoise	*Phocoena phocoena*