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# Compliance with JNCC guidelines during geophysical surveys in UK waters between 2011 and 2020 and long-term trends in compliance

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# Summary

Data from 796 geophysical surveys on the UKCS between 2011 and 2020 were checked and corrected. Data from all or part of 740 surveys were of suitable quality for inclusion in the database. Common errors during data recording in the Marine Mammal Recording Forms were identified. Of these, the most serious were when third party software or an altered version of the forms was used. There was also a common error on the Operations form which, if not corrected, would have given the false appearance of high levels of non-compliance with the requirement for a pre-shooting search. No report or data were submitted for almost one third of surveys consented.

154,643 hours were recorded as monitoring for marine mammals between 2011 and 2020 (102,044 hours visual monitoring and 52,599 hours acoustic monitoring). There were 4,681 sightings or acoustic detections of marine mammals; minke whales and white-beaked dolphins were the most frequently encountered identified species.

Compliance with the mitigation measures contained in the JNCC guidelines for geophysical surveys was assessed for surveys with airguns and for high resolution surveys (defined here as those using high resolution sources other than airguns). Consent conditions were considered where appropriate when assessing compliance.

Compliance with the requirement for a pre-shooting search was generally high for visual searches in daylight (although slightly lower for high resolution surveys and in recent years for airgun surveys) and acoustic searches at night. Standards of pre-shooting searches were sometimes lower for Vertical Seismic Profiling (VSP), where there was sometimes only a single dual role MMO / PAM operator. For all survey types, acoustic searches in daylight (where these were required to complement visual searches) were often absent.

Between 2011 and 2020 there were 158 occasions on surveys using airguns when firing was required to be delayed due to the presence of marine mammals within the mitigation zone. There were 15 occasions when delays were required on high resolution surveys following their inclusion in the JNCC guidelines in 2017. Most delays were due to visual detections. On surveys using airguns delays were required most often due to the presence of dolphins (mainly white-beaked dolphins or common dolphins where identified) or minke whales whereas on high resolution surveys delays were required most often due to the presence of seals (grey or unidentified). Although correct procedures were usually followed there were some occasions when there was no delay and on high resolution surveys there was sometimes no soft start following a delay.

On surveys using airguns compliance with the minimum duration of the soft start was high, particularly in recent years. The reduction in the soft start duration required for small airgun arrays in the 2017 guidelines resulted in increased compliance with the minimum duration but a decline in compliance with the maximum duration on site surveys. VSPs also sometimes had prolonged soft starts. In 2017 increasing the frequency of firing (i.e. decreasing the shot point interval) was no longer included as a recommended method of performing a soft start with airguns, but site surveys often continued to use this method. There was limited information on the progression of the soft start on surveys with large airgun arrays, but from available information it was apparent that the volume of airguns firing by the end of the soft start often exceeded the production volume. For high resolution surveys compliance with the requirement to commence activity with a soft start, where required in the consent, was poor until 2020.

There were relatively few short breaks in activity of less than 10 minutes. In most cases there was adequate monitoring for marine mammals during short breaks in the use of airguns; where monitoring was inadequate this was often due to a lack of monitoring with

PAM when the break occurred at night. On high resolution surveys, most short breaks occurred during daylight and monitoring was mostly absent.

Testing of equipment was commonplace, particularly on surveys with large airgun arrays. Of note was one 3D survey where 55% of occasions when the airguns were used were for testing. Most tests on site surveys, VSP and high-resolution surveys reached full power; on high resolution surveys tests at full power sometimes lacked a soft start when the consent required it.

Of surveys with airguns, site surveys, VSPs and Ocean Bottom Seismic (OBS) surveys were those that most often continued to fire during short line changes. Compliance improved following the revision of the JNCC guidelines in August 2017 to change the time limit for continued firing during a line change to 40 minutes regardless of the size of the array (previously there was a 20-minute limit for large arrays ≥ 500 cu.in., which was difficult to implement on OBS surveys). High resolution surveys often continued activity during short line changes and compliance with time limits was generally good. However, where sub-bottom profilers were used simultaneously with airguns there were some longer line changes when the sub-bottom profilers remained active after the airguns had stopped.

Three-quarters of surveys utilising a single mini-airgun continued to fire during short line changes expected to take less than 40 minutes. Although currently permitted under the guidelines, this represented a significant increase in overall noise input to the marine environment on these surveys.

Procedures to follow when repositioning the geophone on VSP operations were clarified in the 2017 revision of the JNCC guidelines. Reports from VSPs since then have lacked the detail needed to assess compliance properly, although from available data compliance with procedures for repositioning geophones on VSPs was lower than compliance with the equivalent procedures for line changes on other survey types.

The use of PAM increased throughout 2011–2020 with most surveys using PAM by the end of the period. PAM was predominantly used at night; by 2020 there were no occasions when activity commenced at night without some monitoring with PAM beforehand. However, on surveys where consents required that PAM was used to complement the visual search during daylight, operations in daylight often commenced without PAM. There was increasing use of PAM for monitoring prior to starting operations in suboptimal or very poor weather conditions, although this was sometimes as a substitute for visual monitoring.

Although most delays were due to visual detections, there were some delays due to acoustic detections where animals would otherwise have been undetected. Range determination was often difficult with PAM and there was an inconsistent approach regarding whether to delay if marine mammals were detected acoustically prior to operations commencing and there was no estimate of the range. It is recommended that, in the absence of evidence that marine mammals are outside the mitigation zone, there should be a precautionary delay.

When variables other than monitoring method were controlled for, visual detection rates were similar or significantly greater than acoustic detection rates for all species or species groups tested, whether for animals at any range or for animals in the mitigation zone or for animals detected in suboptimal sea conditions. When visual and acoustic monitoring was concurrent, visual detection rates were significantly higher than acoustic detection rates for all species groups tested. It is recommended that during daylight, PAM is only used alongside visual monitoring and not as a substitute for it unless visibility is restricted to the extent that the mitigation zone cannot be seen.

It is recommended that operators of surveys ensure that they engage sufficient personnel to enable compliance with the JNCC guidelines and survey specific consent conditions. The use of PAM to complement visual searches during daylight appeared to be related to the number of PAM operators. Daylight acoustic pre-shooting searches (when required by the consent) were often absent; in most cases where searches were absent there was only one PAM operator. VSPs tended to have fewer personnel than other survey types, with over one third utilising a single dual role MMO / PAM operator, including in locations and seasons where the JNCC guidelines recommend sufficient personnel are employed. Where a single dual role MMO / PAM operator was used there was sometimes no visual pre-shooting search during daylight hours. It is recommended that use of a single dual role MMO / PAM operator is discontinued.

Dedicated MMOs had higher sighting rates than non-dedicated MMOs and were able to detect marine mammals at greater distances. Non-dedicated MMOs were more likely not to use binoculars and often did not have any tool to estimate range. Compliance with pre-shooting searches and soft starts was generally good for both types of MMO, but there were only two occasions when a delay was required when non-dedicated MMOs were used and only one was implemented correctly. Most surveys had data that could be included in the database whether recorded by dedicated MMOs, non-dedicated MMOs or PAM operators, but PAM operators often did not record weather conditions while monitoring.

Potential items for consideration when the JNCC guidelines are next revised are discussed. These include further clarification on staffing levels, use of PAM, soft start methodology, use of a mini-airgun, delays for acoustic detections and reporting.

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# 1 Introduction

Human activities in the marine environment have the potential to impact the species that live there, including marine mammals. In addition to impacts from threats such as fisheries bycatch and pollution, marine mammals are vulnerable to acoustic disturbance from the noise produced by various activities. Impulsive noise in particular poses a higher risk of auditory damage than non-pulsed noise, due to the high peak levels and rapid rise time that characterise impulsive sounds (Southall *et al.* 2007). Impulsive noise results from activities such as geophysical surveys, impact piling and the use of explosives.

Marine mammals are protected in UK waters by a series of regulations. Cetaceans are marine European Protected Species (EPS), listed in Annex IV of the EC Habitats Directive. In the UK, deliberate injury and disturbance of EPS is prohibited under the Conservation of Habitats and Species Regulations 2017 and the Conservation of Offshore Marine Habitats and Species Regulations 2017 and similar legislation for Northern Irish and Scottish inshore waters. The Joint Nature Conservation Committee (JNCC) have produced a suite of best-practice mitigation guidelines to reduce the risk of causing deliberate injury to marine mammals from geophysical surveys, piling and explosives operations, and thus reduce the risk of causing an offence.

JNCC first introduced guidelines for seismic surveys, where the sound from airguns is used to explore the sea floor in the search for oil and gas reserves, in 1995. The guidelines initially only covered cetaceans, but in 1998 were extended to cover all marine mammals. There have been several subsequent revisions, with the latest version in 2017 being extended to include all types of geophysical survey, thus including the use of acoustic sources such as sub-bottom profilers in addition to airguns (JNCC Guidelines for Minimising the Risk of Injury to Marine Mammals from Geophysical Surveys; JNCC 2017). Geophysical surveys conducted on the UK Continental Shelf (UKCS) by the oil and gas industry (O&G) require consent from the Department for Business, Energy, and Industrial Strategy (BEIS). As a statutory consultee JNCC are consulted on all applications for consent and JNCC guidelines inform the conditions of consents.

The JNCC guidelines have various provisions, including the requirement to monitor for marine mammals prior to commencing acoustic activity, known as the pre-shooting search. This monitoring may be visual (e.g. in daylight) by Marine Mammal Observers (MMOs) or acoustic (e.g. at night or in poor visibility) by Passive Acoustic Monitoring (PAM) operators. All MMOs and PAM operators undergo JNCC-recognised training in a mitigation role (https://jncc.gov.uk/our-work/marine-mammal-observer-training/). If any marine mammal is detected within a specified mitigation zone during this search, the start of acoustic activity must be delayed. When it is clear to start, acoustic activity must commence with a soft start, where power is gradually built up over a period of time to allow any nearby undetected animals time to move away before the equipment reaches full power. Further provisions cover aspects such as line changes, breaks in operations and testing of equipment. The primary role of the MMO or PAM operator is to provide advice to enable the crew to comply with the JNCC guidelines and hence mitigate potential negative impacts of geophysical operations on marine mammals. The MMOs and PAM operators record data on the operations, pre-shooting searches and any marine mammals detected on standardised Marine Mammal Recording Forms (JNCC 2012). All data from O&G geophysical surveys within the UKCS are required to be returned to BEIS and JNCC as a condition of consent, where, after appropriate quality checks, they are included in a database.

Analysis of mitigation and monitoring data is important for evaluating the effectiveness of mitigation measures (Nowacek *et al.* 2013; Nowacek & Southall 2016). Previous analyses of JNCC's database have examined compliance with the JNCC guidelines from their

introduction in 1995 up to 2010 (Stone 1997, 1998, 2000, 2001, 2003, 2006, 2015). This report presents the results of an analysis of data from 2011 until the end of 2020. The results are presented in the context of longer-term trends in compliance. The aim of the analysis was to assess the level of compliance with the JNCC guidelines and consent conditions in recent years and consider whether any further revisions to the guidelines are required. The analysis focussed on:

- the pre-shooting search
- delays in firing
- the soft start
- breaks in operations
- testing
- line change
- Vertical Seismic Profiling (VSP)
- Passive Acoustic Monitoring
- MMOs and PAM operators
- trends in operations and compliance over time.

# 2 Methods

## 2.1 Available data

Data from 796 surveys undertaken between 2011 and 2020 were collated for analysis. Data were sourced primarily from the Marine Mammal Recording Forms (Excel spreadsheet), with accompanying information contained in MMO reports (summary reports that accompany the Excel spreadsheets) and close-out reports for the Marine Noise Registry (MNR).

### 2.1.1 Marine mammal observations and effort

Visual searches for marine mammals were carried out during daylight hours on geophysical surveys in UK waters. Observers ranged from biologists experienced in marine mammal surveys to non-scientific personnel; in almost all cases observers had undergone basic MMO training. In addition, PAM was utilised on some surveys during night-time operations and sometimes also during the day.

The Marine Mammal Recording Forms completed by the MMOs and PAM operators comprise four tabs and record details including the following:

- Cover Page: general information about the survey.
- Operations: times of acoustic operations, pre-shooting searches and soft starts, and whether any mitigating action was required.
- Effort: observer / PAM operator, time of monitoring, location, source activity and weather conditions throughout (wind force and direction, sea state, swell, visibility, sun glare and precipitation).
- Sightings / acoustic detections: species (with accompanying descriptions and/or photographs to confirm identification), number of animals, behaviour, closest distance of approach to the source and the source activity at the time of the encounter.

Observers used different methods to estimate the range to animals, with a rangefinder stick (Heinemann 1981) being most often used.

### 2.1.2 Acoustic sources

The observations encompassed a range of geophysical surveys using airguns and/or high-resolution sources. A range of airgun arrays were used between 2011 and 2020; the smallest was 4 cu.in., used on some site surveys, while the largest was 6,300 cu.in. (on a 2D survey). Site surveys and VSPs used arrays with low numbers of airguns and typically lower total volumes (mostly up to 180 cu.in. for site surveys and between 500 and 1,000 cu.in. for VSPs). Larger arrays with greater numbers of airguns and larger total volumes (often over 3,000 cu.in.) were used for 2D, 3D, 4D and OBS surveys. The frequency and source level of the airguns were not always recorded, but from available information, arrays used on 2D, 3D, 4D and OBS surveys typically produced frequencies predominantly up to around 200 Hz, with a source level of around 262 $dB^{pk-pk}$ re. 1 µPa @ 1 m. Arrays used on site surveys and some VSP operations typically produced frequencies predominantly up to around 250 Hz, with a source level of around 242 $dB^{pk-pk}$ re. 1 µPa @ 1 m.

High resolution surveys used additional sources, including sub-bottom profilers (boomers, pingers, sparkers and chirp systems), side-scan sonars and multibeam echo sounders. Chirp, pingers and sparkers were the most frequently used sources. Frequencies and source levels were often not recorded, but where information was available frequencies were 1–10 kHz, 3.5 kHz and 50 Hz–4 kHz for chirps, pingers and sparkers respectively and

source levels were around 212–215 $dB^{pk-pk}$ re. 1 µPa @ 1 m, 224 $dB^{pk-pk}$ re. 1 µPa @ 1 m and 213–222 $dB^{pk-pk}$ re. 1 µPa @ 1 m respectively.

The average number of hours actively collecting data and the distance travelled per day is presented in Table 1. Figures are an average over surveys between 2011 and 2020, apart for site surveys which were between 2014 and 2020 as operational data for high resolution sources other than airguns were only routinely recorded since 2014. Distance is not recorded in the database, but speed over the ground usually is. The duration of shooting was summed for each day of each survey. The average speed was calculated for each day of each survey using only periods when the source was active (i.e. periods of deploying gear, waiting on weather or steaming to site were disregarded, as speed could be lower or higher then). The average speed for each day of each survey was then combined with the duration of shooting for that day of that survey to calculate a distance travelled whilst shooting for each day of each survey.

Results were averaged for each survey type, to get the mean distance while shooting and mean time shooting per operational day (i.e. days when shooting was taking place) for each different survey type. Days with no shooting are not included. Sample sizes are lower for distance than for hours, as there were some days when speed was not recorded.

**Table 1.** Average number of hours actively collecting data and the distance travelled per day.

| Survey type | Distance per day (km) | | | Hours per day | | |
|---|---|---|---|---|---|---|
| | Mean | SE | n | Mean | SE | n |
| 2D | 121.59 | 3.05 | 376 | 14.09 | 0.36 | 399 |
| 3D | 115.93 | 0.84 | 3258 | 13.70 | 0.10 | 3460 |
| 4D | 74.15 | 1.20 | 643 | 8.87 | 0.14 | 656 |
| OBC/OBN | 143.74 | 1.80 | 1083 | 16.66 | 0.21 | 1115 |
| VSP | 4.37 | 1.13 | 163 | 6.62 | 0.42 | 226 |
| Site - total | 82.07 | 1.37 | 1645 | 10.73 | 0.17 | 1794 |
| - of which airguns only | 8.50 | 0.70 | 1645 | 1.06 | 0.09 | 1794 |
| - of which airguns + SBP | 38.05 | 1.34 | 1645 | 4.57 | 0.16 | 1794 |
| - of which SBP only | 35.52 | 1.31 | 1645 | 5.10 | 0.17 | 1794 |

The data indicate that 2D and 3D surveys have longer survey lines covering larger areas, while 4D surveys tend to have a survey area surrounding a platform and lines are not so long. OBC/ OBN surveys have short line changes and therefore spend a greater time (and thus greater distance) shooting each day. VSPs are short in duration, and many are static, hence the low distance for these surveys. Site surveys cover smaller areas with short survey lines, but they also have short line changes and tend to keep sources operational between lines.

## 2.2 Data quality control

MMO reports and/or data received were matched against consents granted by BEIS for geophysical surveys in the years 2011 to 2020. Submissions from 796 surveys were processed, with surveys taking place in separate phases under the same consent treated as separate surveys. 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 times of source activity corresponded between the different tabs in the form.
- that source characteristics within the form corresponded with information in the MMO report.
- that consecutive positions were credible given the time interval and speed of the vessel.
- and that species identity corresponded with the description and/or photographs provided.

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.

Some high-resolution surveys used multiple sources at various times and in various combinations. The Marine Mammal Recording Forms required details of the source(s) to be included on the Cover Page, but there was no facility for distinguishing between different sources within records on the Operations, Effort or Sightings tabs. In some cases, the active source was indicated in the Comments field on the Operations tab. In other cases, this information was gained from examination of the other tabs, the MMO report or the MNR close-out form for the survey. Where it was impossible to tell which source was used when, data were discarded. Information on the source for all records was added to an additional field created post hoc in the Operations, Effort and Sightings tabs.

The quality of data on each of the tabs for each survey (or part thereof) was assessed as being in one of four (or five for the Effort data) categories (Table 2). Data categorised as class 3 or 4 were not included in the database.

**Table 2.** Data quality categories.

| Quality | Description |
|---|---|
| 1 | Good quality, few mistakes |
| 2 | Some mistakes |
| 2b (Effort data only) | Significant number of errors, some records had to be discarded |
| 3 | Many errors or gaps, unable to correct with confidence |
| 4 | Many errors or gaps, unable to be corrected, or missing completely |

After following the quality control process, data from a total of 740 surveys within the UKCS between 2011 and 2020 were available for analysis. Existing data from 1,121 surveys undertaken between 1995 and 2010, that had undergone the same quality control process, were available for comparison of compliance in the longer term.

## 2.3 Analysis of compliance

Only data from surveys within the UKCS were analysed to assess compliance with the JNCC guidelines. Compliance was examined for the years 2011–2020 and is presented as the proportion of occasions meeting the best-practice recommendations contained within the guidelines. Where relevant, examples of good and poor practices are described in more detail. Compliance was assessed in relation to the version of the guidelines that was current at the time. Two versions of the guidelines spanned the period between 2011 and 2020, with the 2010 version being replaced by the 2017 revision in August of that year. From 2014

onwards consents were available alongside most MMO reports and any relevant conditions in the consent were taken into consideration when assessing compliance.

Prior to 2017 the JNCC guidelines only applied to surveys using airguns. In August 2017 the guidelines were extended to cover all geophysical surveys including those using high resolution equipment such as sub-bottom profilers (e.g. boomers, chirp, pingers, sparkers), side-scan sonars and multibeam echo sounders. Compliance was assessed separately for surveys with airguns and for high resolution surveys. Mitigation requirements for both are broadly similar therefore the analysis performed was similar and separate methods are not provided, although results are presented separately.

Surveys that used airguns included site surveys, 2D, 3D, 4D, OBS and VSP surveys. Some site surveys combined the use of small arrays of airguns (typically ≤ 180 cu.in.) or a single mini airgun (≤ 10 cu.in.) with other high-resolution sources. All occasions when airguns (of any size) or a mini airgun were active, whether in combination with other sources or not, were treated as surveys with airguns for assessing compliance.

Only when high resolution sources were used without airguns was compliance assessed separately. These sources were used singly and in numerous different combinations, so they were treated together as a whole. Surveys where some or all survey lines utilised high-resolution sources without airguns included site surveys, debris clearance surveys, pipeline route and pipeline inspection surveys, pre-decommissioning surveys and well abandonment surveys. Data for high resolution surveys mostly covered the period from August 2017 onwards, i.e. when these surveys were included in the guidelines. However, some high-resolution surveys were applying the guidelines before this and submitted reports (received from 2014 onwards); to increase sample size this earlier data is included in some of the analysis.

Where available, tables and figures include data from years prior to 2011 for comparison. Mitigation requirements and recording practices have changed over the years and full operations data prior to 2003 are not included in the database. Therefore, the availability of long-term data varies for different aspects of compliance. Where available, compliance data for earlier years relate to mitigation requirements at the time, as they were in the corresponding version of the guidelines. Geographic areas referred to in the text are shown in Figure 1.

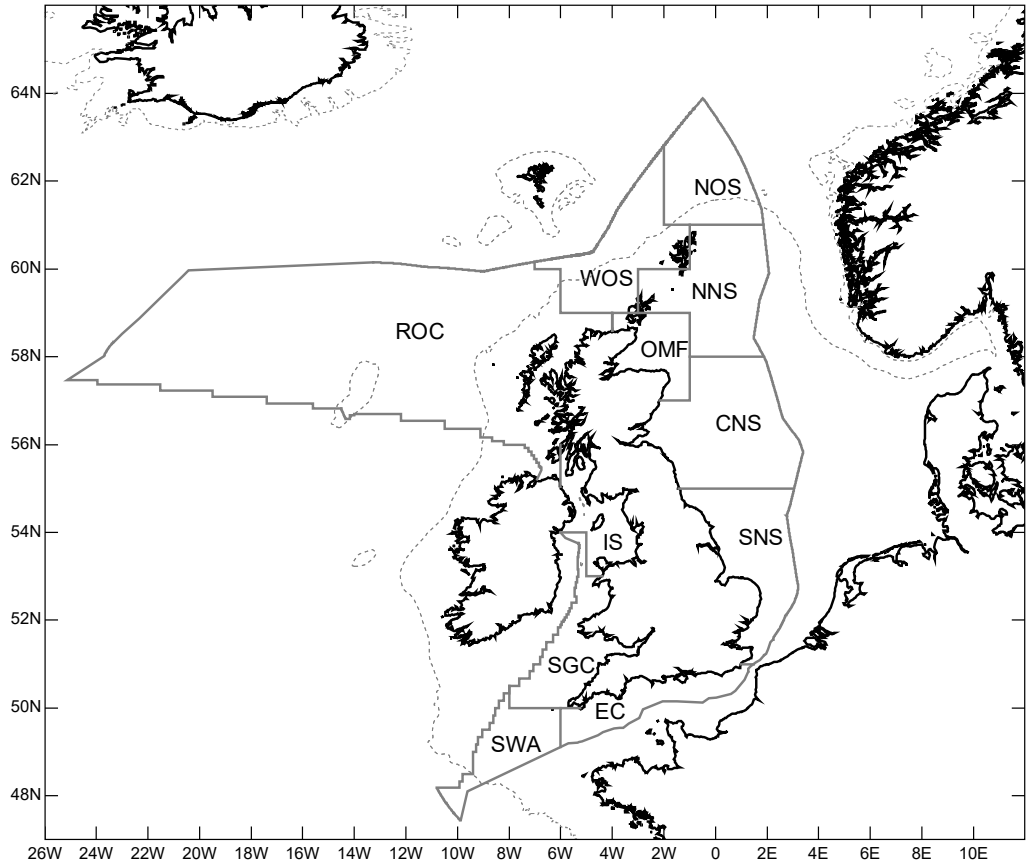


**Figure 1.** Geographic areas within the UKCS used in data analysis: CNS = Central North Sea; EC = English Channel; IS = Irish Sea; NNS = Northern North Sea; NOS = North of Shetland; OMF = Outer Moray Firth; ROC = Rockall; SGC = St George's Channel; SNS = Southern North Sea; SWA = South-west Approaches; WOS = West of Shetland. Dashed line = 200m isobath. Map plotted using DMAP for Windows and contains public sector information (UKCS boundary) licensed under the Open Government License v2.0, from the UK Hydrographic Office.

### 2.3.1 The pre-shooting search

Pre-shooting searches were required any time the source commenced activity after a period of silence. A search of adequate duration was defined as beginning 30 minutes (waters < 200 m depth) or 60 minutes (waters > 200 m depth) before the soft start / commencement of activity and not terminating prematurely. According to the requirements of the JNCC guidelines applying throughout the period, premature termination was classed as a search terminating before the soft start / activity began (prior to August 2017) or a search terminating prior to the start of the survey line (August 2017 onwards).

The proportion of occasions when pre-shooting searches were adequate was assessed for visual searches during daylight hours and for acoustic searches at night. Night-time acoustic searches were assessed for all surveys where PAM was used until 2013; from 2014 onwards, when consents were available for examination, night-time acoustic searches were assessed for all surveys where the consent required PAM to be used at night. The proportion of adequate acoustic pre-shooting searches during daylight hours was assessed for surveys where PAM was used in areas of importance for marine mammals until 2013; from 2014 onwards acoustic searches during daylight were assessed for all surveys where the consent required PAM to be used alongside visual observations in daylight. The proportion of adequate pre-shooting searches at dawn or dusk by visual and/or acoustic means was assessed for all surveys where PAM was used until 2013 and from 2014 onwards for all surveys where the consent required PAM to be used at night.

### 2.3.2 Delays in operations

For all surveys that were wholly within the UKCS (where all source use would have been subject to the JNCC guidelines) the total number of occasions when a delay in operations was required due to the presence of marine mammals in the 500 m mitigation zone was compared to the total number of occasions when the source was used each year. Over the whole period from 2011 to 2020, the chi-squared test was used to compare the observed frequency of delays against the expected frequency on the first day of operations during a survey versus subsequent days.

When assessing compliance, all occasions when a delay was required due to marine mammals in the mitigation zone were included, whether the survey was wholly or partly within the UKCS (provided the marine mammal was detected within the UKCS). Delays were regarded as implemented correctly if there was at least 20 minutes between the last detection in the mitigation zone and the soft start commencing and the subsequent soft start lasted the required minimum duration.

### 2.3.3 The soft start

For all airguns except a mini airgun (≤ 10 cu.in.), the JNCC guidelines require that a soft start is performed when commencing firing (unless testing a single airgun or if there has been a break in firing of less than 10 minutes with no marine mammals in the mitigation zone during the break). The soft start aims to protect any undetected marine mammals in proximity by utilising a gradual build-up of power to allow them to leave the area before full power is reached. The soft start is typically achieved by starting with the smallest airgun in the array and gradually adding in others. Since 2004 the JNCC guidelines permitted alternative means for performing a soft start on site surveys and VSPs in addition to the conventional method of increasing the number of airguns firing. These were increasing the pressure or increasing the frequency of shots (i.e. decreasing the shot point interval). The increasing pressure method was usually used for VSP while the increasing frequency method was mostly used on site surveys (Stone 2015). When the guidelines were revised in August 2017 the recommended methods for performing a soft start were by increasing the number of airguns firing or increasing the pressure; increasing the frequency, whereby the initial shot of a soft start is at the same level as full power, was no longer listed as a method. The method of soft start used for airguns throughout 2011–2020 was determined from reports.

The duration of airgun soft starts was examined for all occasions when firing commenced after a period of silence and full power was reached, with the following exceptions: airgun tests, use of a mini-airgun, short unplanned breaks in firing of less than 10 minutes and the few occasions where there was an exemption from performing a full soft start as agreed with BEIS and JNCC and highlighted within the MMO report or consent. Although a mini airgun is defined in the guidelines as a single airgun with a maximum volume of 10 cu.in., for the purposes of this analysis a single airgun with a volume of 12 cu.in. was also treated as a mini airgun.

Until August 2017 the JNCC guidelines stated that the gradual build-up of power should always be at least 20 minutes to allow adequate time for marine mammals to leave the area. The revision of the guidelines in August 2017 allowed a shorter (minimum 15 minutes until full power) soft start for airgun arrays with a maximum volume of 180 cu.in. The proportion of soft starts that lasted the required minimum duration (from commencement until full power) as specified in the guidelines was assessed, as was the proportion of occasions when there was no soft start.

The proportion of soft starts exceeding the maximum permitted duration (from the beginning of the soft start until the start of the survey line) was also assessed. The maximum duration specified in the guidelines is 40 minutes, except for arrays with a maximum volume of 180 cu.in. since August 2017, where the maximum is 25 minutes.

MMO reports were examined for information on the progression of airgun soft starts. Not all reports gave details of how the soft start was performed, as this information is not required as a standard, but for those that did, the maximum volume of airguns firing during the soft start was compared to the volume fired during production. Very little information was available on the progression of the soft start for larger airgun arrays after 2014.

Since August 2017 the JNCC guidelines have required that mitigation measures are applied to the use of high-resolution sources. However, the guidelines acknowledge that for some electromagnetic sources a soft start is not possible and recommend that if this is the case it is highlighted in the application for consent. When considering compliance with the soft start for high resolution surveys only those surveys where the consent stated that a soft start must be used were included in the analysis. Where the consent required a soft start, the minimum duration specified was 20 minutes, therefore this was the minimum duration against which compliance was assessed. No maximum duration was stated in consents, but a 40-minute maximum from the commencement of the soft start until the start of the survey line was assumed for this analysis, in line with the maximum given in the guidelines for airguns.

### 2.3.4 Breaks in operations

Short breaks in operations of up to 10 minutes do not require a soft start to recommence, although monitoring is required to be undertaken to ensure no marine mammals are in the mitigation zone before activity resumes. Prior to August 2017 this provision only applied to unplanned breaks, but since then there has been provision for planned breaks also. The 2017 version of the JNCC guidelines makes a distinction between unplanned and planned breaks with regards to the duration of monitoring required before activity resumes; monitoring is required to commence 20 minutes prior to the break if the break is planned, whereas for unplanned breaks it must commence as soon as possible after the break occurs.

Reports did not always clarify whether short breaks were planned or not, so the analysis considered all breaks in operations of up to 10 minutes duration. However, in some cases the circumstances of the break suggested whether it was planned or unplanned. The number of short breaks and the mean and maximum duration were assessed, together with the proportion of occasions when monitoring during the break was adequate. For monitoring to be considered adequate it had to commence during (or before) the break and continue until activity resumed; additionally, for breaks since August 2017 that could be considered as planned, monitoring was only regarded as adequate if it commenced 20 minutes prior to the break.

Any breaks in firing longer than 10 minutes would have required a full pre-shooting search and soft start to recommence and were therefore included in assessments of compliance with those requirements.

### 2.3.5 Source testing

The mean number of tests per survey and the proportion that immediately preceded a survey line (with no break in activity between the test and the line) were determined. For tests immediately preceding a line it was impossible to distinguish from the data what proportion of the activity constituted actual testing and what proportion was for building up to the level required for the line, so the mean duration of these tests was assessed from the

start of activity until the start of the survey line. The mean duration of tests conducted separately from a line, where all activity was for the purpose of the test, was measured from the start until the end of activity. The proportion of tests where full power was reached was also determined; for these tests the mean duration of the soft start and the proportion of soft starts meeting the required minimum duration were assessed.

### 2.3.6 Line changes

The proportion of occasions when airguns continued to fire during line changes was determined; this is only permitted if the line change is expected to be completed within a given duration. Prior to August 2017 the permitted line change duration within which airguns could continue firing depended on the array volume; for arrays of 500 cu.in. or more the threshold duration was 20 minutes, while for array volumes of 180 cu.in. or less the threshold duration was 40 minutes. In August 2017 the threshold duration was changed to 40 minutes for all arrays. Surveys prior to August 2017 were therefore analysed separately from later surveys, with the former assigned to categories (≤ 180 cu.in. or ≥ 500 cu.in.) based on the reported airgun array volume. Data were examined to determine how many line changes where the airguns continued firing were within or exceeded the respective specified time limits. Surveys where there were exemptions allowing firing to continue during slightly longer line changes were assessed separately.

The incidence of some procedures during line changes that were not in full compliance with the guidelines was also examined, including continuing to fire for a while after the end of a survey line before deciding to stop, keeping sub-bottom profilers active while airguns stopped during a line change and use of a ‘mitigation gun’ during line changes / repositioning geophones.

Although the guidelines make no distinction between a mini-airgun and other small airgun arrays in relation to line changes, one reason for allowing firing to continue during short line changes is because of the difficulty in performing a full soft start in a limited time period. As a soft start is not required for a single mini-airgun there is less benefit in continuing to fire a mini-airgun during line changes, but such a practice creates additional noise. The prevalence of continued firing during short line changes with mini airguns was therefore also considered.

Since August 2017 the JNCC guidelines have recommended the same procedures are used during line changes with high resolution sources as are used for airguns. The number of line changes where the source remained active within or exceeding the permitted duration was determined.

### 2.3.7 VSP operations

During VSP operations geophones may be lowered to different levels within a well with shots being fired at each level and periods of repositioning of the geophone between levels. Prior to August 2017 there was no specific guidance on what to do when repositioning geophones during VSP operations. In August 2017 the JNCC guidelines clarified that repositioning of geophones on VSPs was to be treated the same as a line change, so firing may continue if the repositioning is expected to be completed within 40 minutes. The guidelines require that if firing continues during repositioning of geophones, then the interval between shots should not exceed five minutes. Reports from VSPs were examined to gather information on the procedures used while repositioning, including the use of ‘mitigation shots’.

The number of VSPs where there was a single person undertaking a dual role as MMO / PAM operator was also examined and the choice of monitoring method for pre-shooting searches during daylight hours was assessed where this was the case.

### 2.3.8 Passive Acoustic Monitoring

#### 2.3.8.1 Use of PAM on surveys

The proportion of surveys using PAM each year was determined. Use of PAM according to survey type and location were also considered.

For source activity commencing at night, in suboptimal weather conditions or in very poor weather conditions, the number of occasions when there was an acoustic search beforehand was compared to the number of occasions when there was no acoustic search. For suboptimal or very poor weather conditions this could only be done for soft starts where the weather conditions beforehand had been recorded on the Effort form. Suboptimal weather conditions were defined as 'choppy' or 'rough' sea states (with descriptors corresponding to those of Beaufort sea-states 4–5 for 'choppy' seas and 6+ for 'rough' seas), 'medium' (2–4 m) or 'large' (greater than 4 m) swell height or 'moderate' (1–5 km) or 'poor' (less than 1 km) visibility. Very poor weather conditions were defined as 'rough' sea state, 'large' swell, or 'poor' visibility.

Where PAM was used, the number of surveys using it routinely in the daytime to complement the visual search was assessed; routine use was defined as being at least 50% of occasions when activity commenced. The number of PAM operators was examined for surveys using / not using PAM routinely in daytime. Where the consent required that PAM was used to complement the visual search in daytime, the number of occasions when operations commenced with acoustic monitoring beforehand was compared to the number without.

The number of delays for marine mammals detected visually, acoustically or by both methods was compared. For surveys with airguns over the period from 2011 to 2020, the chi-squared test was used to compare the observed frequency of delays against the expected frequency for visual versus acoustic monitoring, allowing for differences in the time spent monitoring with each method.

#### 2.3.8.2 Detection rates using PAM compared to visual sighting rates

The data were examined to see which marine mammal species were identified using PAM and which were most detected. Several variables can influence visual detection rates, for example weather conditions influence the ability of observers to detect marine mammals (e.g. Northridge *et al.* 1995; Teilmann 2003; Hammond *et al.* 2013). To assess the influence of weather on the ability to detect marine mammals by either visual or acoustic means during geophysical surveys, for each monitoring method matched samples were used to compare detection rates of cetaceans (all species) at different conditions of sea state, swell and (for visual monitoring) visibility. For each matched sample the survey, source, source activity and weather conditions other than the one under consideration were the same. 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 and a value for $F_r$ calculated with the associated probability determined with reference to the $\chi^2$ distribution. For significant results, multiple comparisons of pairs of treatments were tested using the Wilcoxon signed ranks test to determine where the significant differences lay, with the resulting p-values adjusted using the Bonferroni correction due to the increased risk of a type 1 error when using multiple comparisons.

To assess the effectiveness of PAM compared to visual monitoring, sighting, and acoustic detection rates per hour of visual / acoustic monitoring were compared on surveys where PAM was employed, using only sightings or acoustic detections with accompanying effort data. Matched pairs were used to compare visual versus acoustic detection rates for

periods during each day of each survey when sea state, swell and source activity were the same, thereby controlling for any influence of location, season, weather, survey type and noise. Both airgun surveys and high-resolution surveys were used, as the matched pairs controlled for source. Visibility and sun glare were not accounted for as PAM operators did not record these. Therefore, visual monitoring may have included periods of poor visibility or strong sun glare, leading to suboptimal conditions for detecting marine mammals visually. The process of identifying matched pairs eliminated many sightings / acoustic detections that occurred during days when variables could not be matched, reducing sample sizes. However, such an approach was necessary to reduce potential bias in the results due to external variables.

Results are presented for individual species where sample size permitted. Many acoustic detections were not identified to species level, so groups of combined species were also used (e.g. all cetaceans or all delphinids). These combined species groups comprised all identified and unidentified animals within that taxonomic grouping.

The matched pairs (acoustic versus visual detection rates) 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 the magnitude of the difference (i.e. by how much is it greater). The Wilcoxon signed ranks test can be performed on small samples, with significant results being able to be detected with sample sizes as low as five matched pairs (Siegel & Castellan 1988). For larger samples the test statistic $T^+$ is approximately normally distributed so in these cases z was calculated and its associated probability was determined by reference to tables for the normal distribution.

To determine the effectiveness of PAM for monitoring the presence of marine mammals within the 500 m mitigation zone compared to visual methods, the above analysis was repeated using only detections within the mitigation zone. To test the effectiveness of PAM compared to visual methods for detecting marine mammals in suboptimal sea conditions the analysis was repeated for detections at any range in ‘choppy’ or ‘rough’ sea states or ‘medium’ or ‘large’ swell.

Although the above analysis compared sightings and acoustic detections in the same conditions within the same day of the same survey, they were not necessarily from monitoring that was concurrent. Periods where visual and acoustic monitoring were concurrent (visual and acoustic effort records from the same survey shared the same start and end times) were identified, enabling a direct comparison of sightings and acoustic detections at those times. Sample sizes were lower for concurrent monitoring, so combined species groups (all cetaceans and all delphinids) were tested for detections at any range, using the Wilcoxon signed ranks test.

#### 2.3.8.3 Detection rates of different PAM systems

Six different PAM systems were recorded as being used on geophysical surveys between 2011 and 2020. Mean detection rates per survey for the six systems were compared, initially for all areas of the UKCS. To reduce bias due to differential use of the various systems in different areas, detection rates were also compared for the Central and Northern North Sea only. The different PAM systems are represented by letter and not identified.

#### 2.3.8.4 Range estimation using PAM

An estimate of the range from the source of any marine mammals detected (either visually or acoustically) is needed to inform decisions regarding mitigation, in particular the need to delay operations. Data from surveys with airguns and high-resolution surveys were

combined when considering the ability of PAM to estimate range. The proportion of acoustic detections with no estimate of range was compared to the proportion of visual detections with no estimate of range. The accuracy of range estimation by both monitoring methods was indicated by the proportion of detections where range was more detailed than to the nearest 100 m (for detections within 1 km) or 500 m (for detections beyond 1 km). The distribution of range estimates for visual and acoustic detections was compared by determining the proportion of detections of marine mammals within a given range of the source. This was tested using the Kolmogorov-Smirnov test, a non-parametric test that compares the cumulative distribution of two samples by searching for any point at which the two cumulative distributions are 'too far apart'.

### 2.3.9 MMOs and PAM operators

Requirements for MMOs and PAM operators are advised during the consent process for individual surveys. The mean number of dedicated MMOs and PAM operators per survey each year was determined for surveys with airguns (since the introduction of the JNCC guidelines in 1995) and for high resolution surveys (since 2014). For the period 2011–2020 the mean number of dedicated MMOs and PAM operators were compared for the various survey types. The number of PAM operators was examined on surveys where PAM was used routinely during the day (on at least 50% of occasions when operations commenced during daylight) or where PAM was used mainly at night.

Detection rates of dedicated and non-dedicated MMOs were compared, firstly at all times, then only during good weather conditions when detection of marine mammals would have been easier ('glassy' or 'slight' sea states, swell less than 2 m and visibility greater than 5 km; 'glassy' or 'slight' sea states have descriptors corresponding to those of Beaufort sea-state 3 or less). Only sightings with accompanying effort data were used. The median and maximum ranges to animals at first detection were also compared. The proportion of each type of observer not using binoculars or a range-finding tool was also assessed. Implementation of the guidelines was examined by comparing three key areas of compliance (pre-shooting searches, delays, and soft starts) for each type of observer.

The data recorded by dedicated MMOs, non-dedicated MMOs and PAM operators were compared by examining the proportion of surveys where data were of acceptable quality for inclusion in the database, the proportion of effort records where weather was recorded in full or not at all and the proportion of sightings or acoustic detections that had accompanying effort data. For PAM operators only those surveys where PAM was employed were used.

### 2.3.10 Trends in operations

Information on airgun array sizes, where known, was used to identify any trends in operational volume over time. Trends in the location of surveys were examined, for airgun surveys over the period 2011–2020 and for high resolution surveys since 2014. Data from all years were combined to determine the seasonality of surveys for each survey type; surveys overlapping more than one month were assigned to the month of commencement.

Submission of MMO reports and data between 2011 and 2020 was examined by matching consents issued for geophysical surveys each year to the MMO reports and/or data received. Surveys that were cancelled or where there was no submission, but the consent had not yet expired, were excluded.

# 3 Results

## 3.1 Quality of data

MMO reports and/or data were submitted for 69% of geophysical surveys taking place for which consent was granted between 2011 and 2020 (excluding surveys known to have been cancelled or those where the consent had not yet expired). Of the surveys where neither a report nor data were submitted, it is not known whether there were any MMOs or PAM operators on board or whether there was any mitigation to reduce the risk to marine mammals.

Of the 796 UK surveys that were processed, data from 30 were completely missing and 26 had data of such poor quality that corrections could not be made (these included seven where it was not possible to distinguish which source(s) were being used when). Of the remaining 740 surveys, data from part or all the surveys were able to be included in the database following checks and corrections. A reduction in numbers of surveys between 2015 and 2017 (Table 3) reflects a reduction in the numbers of surveys consented and therefore reports submitted to JNCC in those years. A reduction in the number of surveys in 2020 was partly due to the Covid-19 pandemic and partly due to some reports not being submitted in time to be analysed.

**Table 3.** Number of UK geophysical surveys processed per year where data were of sufficient quality for inclusion in the database.

| Year | Number of surveys |
|---|---|
| 2011 | 124 |
| 2012 | 122 |
| 2013 | 112 |
| 2014 | 78 |
| 2015 | 52 |
| 2016 | 46 |
| 2017 | 48 |
| 2018 | 63 |
| 2019 | 75 |
| 2020 | 20 |

Cover Page and Sightings data was generally of higher quality than Operations or Effort data (Table 4). However, for all four forms, most data were usable and able to be added to the database following checks and corrections.

**Table 4.** Proportion of surveys (or part surveys) with data in the different quality categories between 2011 and 2020. Those classified as Class 3 or 4 were discarded from the analysis.

| **Form** | **Class 1** (Good quality, no / few mistakes) | **Class 2** (Some mistakes but corrected) | **Class 2b** (Only part data usable) | **Class 3** (Corrections not confident) | **Class 4** (Missing or corrections impossible) |
|---|---|---|---|---|---|
| Cover Page | 72% | 20% | - | 1% | 6% |
| Operations | 41% | 50% | - | 2% | 6% |
| Effort | 49% | 35% | 6% | 3% | 8% |
| Sightings | 66% | 28% | - | 0% | 7% |

The most common errors for each of the four forms are listed below:

Cover Page:

- location missing or vague (e.g. North Sea) rather than quadrants and blocks
- lack of detail about the source (particularly sub-bottom profilers)
- details for the source not matching those noted in the MMO report
- not including units (dB re. 1 µPa or bar metres) for intensity
- lack of detail for PAM (where used)
- the Cover Page was missing, and information had to be retrieved from the MMO report.

Operations:

- starting a new record at midnight (guidance on the forms says this should not be done for the Operations form)
- inconsistency about how to record times of test firing
- using a single record for all VSP operations rather than separating records between different levels (where airguns continued firing during repositioning of the geophone);
- missing the time when the source stopped
- recording PAM search times in the visual search columns, and vice versa
- search times not matching times recorded as monitoring on the Effort form
- recording the time of the end of the visual search / PAM as the time the soft start began (since 2017, the JNCC guidelines have required monitoring to continue until data acquisition has begun)
- mixing the codes for dawn and dusk
- not including operations data for a mini airgun
- not using the Comments field to distinguish survey lines done with different sources (where these varied during a survey)
- not using the Comments field to identify activity within UK waters (where surveys were only partly in the UKCS).

Effort:

- the date in the hour before midnight being that of the next day (i.e. dates used BST while times were recorded correctly in UTC)
- source activities not agreeing with that recorded on the Operations form;
- not starting a new record when source activity changed
- using ‘variable’ for source activity over a length of time rather than showing the times at different source activities
- using ‘soft start’ for the source activity during the pre-shooting search when ‘not active’ should have been used (particularly on VSPs)
- inconsistency in recording source activity between survey lines where there were multiple sources and only some continued to be active during the line change.
- not entering a new record each hour whilst monitoring
- adding an additional record at the end of a monitoring period with the same start and end times and positions
- not starting a new record at midnight (guidance on the forms says this should be done for the Effort form)
- records overlapping in time
- not noting the change in degrees of latitude or longitude when the vessel moved between one degree and the next
- recording positions that were not credible given the speed and last position of the vessel
- where visual and PAM effort was recorded at the same times, discrepancies in the positions recorded
- errors in recording whether the position was east or west of Greenwich
- recording positions and depths to many decimal places
- lack of detail regarding weather (particularly for PAM)
- using the observer’s initials rather than name (widespread use of initials rather than a name causes difficulties in the analysis as many observers share initials).

Sightings:

- missing or inadequate descriptions of animals
- recording behaviours in the Comments or Description field instead of the Behaviour field
- source activity at the time of the sighting not matching that recorded on the Operations form
- not recording the time or distance of the closest approach
- for animals that were in the mitigation zone, not recording the time they entered or left the zone
- the time of closest approach or the time animals entered or left the mitigation zone being outside the times recorded as the start and end times of the encounter

- recording distances from the source during the soft start when the animals were not present during the soft start
- errors in recording whether the position was east or west of Greenwich
- not entering the number of animals for acoustic detections (the forms say to enter 1 if the number cannot be determined)
- acoustic detections close in time (less than 10 minutes) recorded as separate detections without justification as to why they were considered to be different animals
- including age classes (adult, juvenile or calf) for acoustic detections (where animals were recorded as only detected acoustically)
- duplicating records of animals that were detected both visually and acoustically
- not assigning the same sighting reference number to each species record in a mixed species sighting.

Errors common to all four forms:

- errors in the regulatory reference number for some records within a survey
- using BST for some records instead of UTC
- wrong dates
- changing the format of date fields to month/day/year instead of day/month/year for some records within a survey
- spelling the ship's name differently between the forms (which causes issues with analysis where data needs to be linked on the ship's name)
- inconsistency in spelling the observer's name (which could lead to problems in analysis when accounting for inter-observer variation)
- times for some records being in a format where a hidden date was associated, usually a random date (e.g. 1 January 1900)
- including seconds in time
- changing validation settings to allow an entry other than those in a drop-down list
- changing the structure of forms to add extra columns (that need to be removed to be compatible with the database)
- information in the Comments field exceeding the character limit
- where surveys were prolonged and personnel on different rotations reported separately there was a greater tendency for sections to be missing or sometimes duplicated
- records missing for the undershoot vessel.

The quality of Operations data reduced from 2017 onwards, due mainly to an error in interpretation of the forms. MMOs and PAM operators routinely record the end of their search on the Operations form as the time when the soft start begins. Prior to 2017 this was not an issue as MMOs, and PAM operators were only required to monitor for marine mammals until the soft start began. However, since August 2017 the guidelines require that they continue monitoring throughout the soft start until data acquisition has begun (i.e. until the start of the survey line). Recording the search as ending when the soft start begins therefore results in an apparent non-compliance. Records on the Effort form were used to ascertain whether monitoring continued and the end of search time on the Operations form

was amended where appropriate to prevent false non-compliances appearing during analysis. Almost every end of search time on Operations forms since August 2017 had to be amended, resulting in many acceptable Operations data since then being assessed as class 2 rather than class 1.

There were also significant issues where the standard Excel recording forms were not used. For example, some MMO/PAM providers got their staff to use third party software to record their observations which then automatically populated the Excel forms rather than the MMOs and PAM operators entering data directly into the Excel forms. In other cases, an amended version of the Excel forms was used, with differences in structure from the standard forms. Both the use of third-party software and the amended forms caused numerous issues that required extensive and time-consuming corrections during checking. There were also problems when importing the data from these surveys into the database, as the recorded times failed to be recognised as such and failed to import into the database. As a result, over 60,000 times recorded during these surveys needed remedial action (in some cases manual re-entry) to render them usable.

Some MMO reports, particularly for high resolution surveys, were not written by the MMOs / PAM operators but instead by in-house staff of survey companies / consultancies. Such reports often followed a standard format adopted by the company with details (e.g. regarding the source) amended for each project. However, there were multiple instances where details contained within the report did not match those contained within the data; similarities with reports from previous projects suggested that these details had been copied from earlier reports and did not relate to the current project.

## 3.2 Overview of survey effort and species encountered

A total of 154,643 hours 03 minutes were recorded as monitoring for marine mammals during geophysical surveys within the UKCS (wholly or partly) between 2011 and 2020, comprising 102,043 hours 59 minutes visual monitoring and 52,599 hours 04 minutes acoustic monitoring. Acoustic sources were active for 62% of the total time spent monitoring.

There were 4,681 sightings or acoustic detections of marine mammals, comprising 34,656 individuals (Table 5). Unidentified dolphins were encountered most often, but of identified species the minke whale was the most frequently encountered, followed by white-beaked dolphin, long-finned pilot whale, harbour porpoise and grey seal. Killer whales, common dolphins and sperm whales were also regularly seen, with other species occurring less frequently.

**Table 5.** Species of marine mammal encountered during geophysical surveys within the UKCS from 2011–2020.

| Species | No. sightings / acoustic detections | No. individuals |
|---|---|---|
| Seal sp. | 202 | 258 |
| Grey seal | 222 | 258 |
| Harbour seal | 23 | 28 |
| Cetacean sp. | 513 | 1,823 |
| Whale sp. | 314 | 734 |
| Large whale sp. | 58 | 81 |
| Humpback whale | 13 | 19 |
| Blue whale | 1 | 1 |
| Fin whale | 61 | 165 |
| Sei whale | 13 | 38 |
| Humpback / sperm whale | 2 | 2 |

| Species | No. sightings / acoustic detections | No. individuals |
|---|---|---|
| Blue / fin / sei whale | 9 | 43 |
| Fin / sei whale | 50 | 137 |
| Fin / sei / humpback whale | 4 | 7 |
| Fin / sei / blue / humpback whale | 149 | 389 |
| Fin / blue whale | 19 | 71 |
| Sperm whale | 112 | 170 |
| Medium whale sp. | 29 | 31 |
| Minke whale | 525 | 637 |
| Beaked whale sp. | 3 | 3 |
| Northern bottlenose whale | 3 | 3 |
| Long-finned pilot whale | 265 | 6,865 |
| Killer whale | 116 | 887 |
| Delphinid sp. (dolphin, long-finned pilot, killer, false killer whale) | 102 | 456 |
| Dolphin sp. | 1,020 | 8,377 |
| Dolphin sp. (not porpoise) | 7 | 30 |
| Risso's dolphin | 15 | 94 |
| Bottlenose dolphin | 35 | 285 |
| White-beaked dolphin | 386 | 4,702 |
| Atlantic white-sided dolphin | 95 | 5,107 |
| *Lagenorhynchus* sp. | 14 | 598 |
| Common dolphin | 114 | 1,505 |
| Striped dolphin | 1 | 50 |
| Common / striped / white-beaked / Atlantic white-sided dolphin | 4 | 45 |
| Common / Atlantic white-sided dolphin | 6 | 218 |
| Harbour porpoise | 233 | 539 |
| **Total** | **4,681*** | **34,656** |

* Mixed species sightings / detections are only counted once in the total.

## 3.3 The pre-shooting search

### 3.3.1 Surveys using airguns

During the period 2011–2020 compliance with the requirements for visual pre-shooting searches on surveys using airguns initially increased, reaching a peak of 97% of searches being of adequate duration in 2016 (Table 6). There was then a slight reduction in standards, dropping to 89% by 2020, although sample sizes were relatively low for that year. In some years pre-shooting searches on VSP operations were of a lower standard compared to other types of surveys, although sample sizes for VSPs were relatively low. For all survey types, in some cases there was no pre-shooting search (accounting for 38% of all inadequate visual searches); in other cases, a search was conducted but it ended prematurely (36% of inadequate searches) or did not start far enough in advance of firing (27% of inadequate searches).

**Table 6.** Percentage (and sample size) of adequate duration visual pre-shooting searches during daylight on surveys wholly within the UKCS when airguns were used.

| Year | Site | VSP | 2D | 3D | 4D | OBS | Total |
|---|---|---|---|---|---|---|---|
| 2003 | 61.4 (425) | 83.3 (6) | 87.0 (92) | 83.6 (366) | 75.5(143) | 95.6(136) | **76.2(1,168)** |
| 2004 | 72.9 (575) | 83.3 (12) | 95.2 (21) | 100.0(283) | 95.2(227) | 100.0 (38) | **85.3(1,156)** |
| 2005 | 76.2 (621) | 100.0 (5) | 90.8 (251) | 94.3 (690) | 97.4(427) | - | **88.9(1,994)** |
| 2006 | 58.6 (636) | 80.0 (10) | 77.9 (190) | 95.6 (720) | 83.7(374) | 91.0 (78) | **79.7(2,008)** |
| 2007 | 65.1 (421) | 61.1 (18) | 96.6 (298) | 97.2 (361) | 98.6(558) | 100.0 (11) | **89.1(1,667)** |
| 2008 | 84.2 (349) | 63.6 (11) | 97.1 (105) | 95.9 (586) | 95.2(352) | 90.0 (20) | **92.6(1,423)** |
| 2009 | 89.8 (498) | 100.0(17) | 84.6 (65) | 74.0 (342) | 95.6(205) | 97.3(110) | **86.9(1,237)** |
| 2010 | 73.5 (558) | 63.6 (44) | 89.8 (49) | 95.3 (485) | 91.4(452) | 87.2(234) | **85.7(1,822)** |
| 2011 | 91.8 (680) | 84.6 (26) | 78.6 (84) | 88.7 (621) | 90.8(153) | 83.3(1,003) | **87.1(2,567)** |
| 2012 | 93.2 (936) | 72.2 (36) | - | 89.2(1,051) | 96.9(260) | 92.0(801) | **91.4(3,092*)** |
| 2013 | 93.7(1,106) | 94.7 (38) | 94.8 (58) | 96.6(1,310) | 94.0(615) | 100.0 (9) | **95.0(3,136)** |
| 2014 | 93.3 (674) | 92.0 (25) | 100.0 (63) | 96.8 (412) | 97.1 (69) | 99.1(650) | **96.4(1,893)** |
| 2015 | 95.5 (483) | 95.0 (20) | 92.9 (14) | 96.1 (253) | 100.0(11) | 96.7(302) | **95.9(1,083)** |
| 2016 | 96.6 (560) | 88.9 (9) | 97.7 (131) | 97.8 (136) | 100.0(109) | 97.9(418) | **97.4(1,363)** |
| 2017 | 98.5 (272) | 85.0 (20) | 89.4 (94) | 100.0 (50) | 95.1 (61) | 93.1(856) | **94.2(1,353)** |
| 2018 | 96.5 (283) | 88.9 (9) | 100.0 (6) | 97.7 (426) | 92.9(212) | 94.2(329) | **95.7(1,265)** |
| 2019 | 93.0 (370) | 94.4 (54) | 100.0 (3) | 91.1 (316) | 100.0 (9) | - | **92.4 (752)** |
| 2020 | 93.3 (90) | - | - | - | 77.1 (35) | - | **88.8 (125)** |

* The total for 2012 includes 8 daylight searches during seismic while drilling, where 12.5% were of adequate duration.

The standard of acoustic pre-shooting searches at night was similar to visual searches, although again were lower for VSP surveys in some years (Table 7). Again, standards peaked in 2016 (at 98% searches being adequate), however there was not the same marked drop in standards in 2020 as there was for visual searches. Of those occasions where there was not an adequate acoustic search at night, 35% were due to the search being absent; searches that started late or ended prematurely accounted for 34% and 31% of inadequate searches respectively.

Acoustic searches to accompany visual searches in daylight were much more variable and sometimes of a very low standard (Table 8); in most (91%) cases where the search was inadequate this was due to there being no daytime acoustic search to accompany the visual search. On 87% of these occasions (where there was no acoustic search when required in daytime) there was only one PAM operator on board.

**Table 7.** Percentage (and sample size) of adequate duration acoustic pre-shooting searches at night within the UKCS when airguns were used (until 2013 this includes all surveys where PAM was used; from 2014 this includes all surveys where PAM was required at night as a condition of consent).

| Year | Site | VSP | 2D | 3D | 4D | OBS | Total |
|---|---|---|---|---|---|---|---|
| 2003 | - | - | 21.4(14) | 0.0 (68) | - | - | **3.7 (82)** |
| 2004 | - | - | - | - | 0.0 (53) | - | **0.0 (53)** |
| 2005 | - | - | 0.0(31) | - | - | - | **0.0 (31)** |
| 2006 | 72.7 (11) | - | 87.9(58) | 82.5(103) | - | 75.0 (4) | **83.5(176)** |
| 2007 | - | - | 100.0 (9) | - | 97.3(111) | - | **97.5(120)** |
| 2008 | 79.2 (77) | - | - | 90.1 (81) | 63.0 (92) | 100.0 (2) | **77.0(252)** |
| 2009 | 13.0 (46) | 100.0 (1) | 0.0 (9) | 45.5 (55) | - | - | **28.8(111)** |
| 2010 | 97.0 (66) | 100.0 (3) | 25.0 (4) | 97.9(140) | 97.8 (46) | 41.4 (29) | **91.0(288)** |
| 2011 | 93.2(118) | 100.0 (7) | 100.0(27) | 92.6(244) | - | 92.5(159) | **93.2(555)** |
| 2012 | 95.2(105) | 93.8 (16) | - | 92.2(528) | 87.8(131) | 92.7(302) | **92.3(1,104*)** |
| 2013 | 87.9(331) | 83.3 (6) | 97.3(37) | 96.7(783) | 97.6(246) | - | **94.7(1,403)** |
| 2014 | 98.3 (59) | 100.0 (4) | 100.0(20) | 94.8(116) | 89.7 (29) | 100.0 (47) | **96.4(275)** |
| 2015 | 65.0 (40) | 100.0 (2) | 100.0 (3) | 98.5(132) | 100.0 (5) | 98.6 (72) | **93.3(254)** |
| 2016 | 98.3(177) | 100.0 (1) | 98.9(90) | 95.9 (74) | 100.0(35) | - | **98.1(377)** |
| 2017 | 95.6(137) | 80.0 (5) | 100.0(21) | 100.0 (20) | 93.8 (32) | 97.6(205) | **96.7(420)** |
| 2018 | 98.1 (54) | 66.7 (3) | 100.0(14) | 92.3(195) | 79.0 (62) | 96.4(193) | **92.9(521)** |
| 2019 | 94.7 (38) | 86.7 (15) | - | 99.0 (98) | 100.0 (6) | - | **96.8(157)** |
| 2020 | 96.8 (63) | - | - | - | 83.3 (12) | - | **94.7 (75)** |

* The total for 2012 includes 22 night-time searches during seismic while drilling, where 100% were of adequate duration.

**Table 8.** Percentage (and sample size) of adequate duration acoustic pre-shooting searches in daylight within the UKCS when airguns were used (until 2013 this includes all surveys in areas of importance for marine mammals where PAM was used; from 2014 this includes all surveys where PAM was required to complement the visual search during daylight as a condition of consent).

| Year | Site | VSP | 2D | 3D | 4D | OBS | Total |
|---|---|---|---|---|---|---|---|
| 2009* | 0.0 (39) | 0.0 (2) | 0.0 (19) | 1.7 (119) | - | - | **1.1(179)** |
| 2010 | 65.7(105) | 100.0 (1) | - | - | 89.7(185) | 22.5(138) | **62.2(429)** |
| 2011 | 33.7 (92) | 100.0 (1) | 36.4 (44) | 15.0 (193) | - | 76.9(576) | **57.3(906)** |
| 2012 | 58.4(255) | 72.7 (11) | - | 21.3 (287) | - | 81.5(353) | **56.1(914**)** |
| 2013 | 73.0(137) | 14.3 (7) | 0.0 (7) | 30.2 (182) | 75.0(120) | - | **54.3(453)** |
| 2014 | 92.9 (14) | 16.7 (6) | - | 76.7 (154) | - | - | **75.9(174)** |
| 2015 | - | 0.0 (13) | - | - | - | - | **0.0 (13)** |
| 2016 | 92.0 (25) | - | - | - | - | 1.0(418) | **6.1(443)** |
| 2017 | - | 14.3 (7) | - | - | - | - | **14.3 (7)** |
| 2018 | 26.3 (19) | 44.4 (9) | 0.0 (6) | 5.9 (51) | - | - | **14.1 (85)** |
| 2019 | 0.0 (12) | - | - | 54.3 (140) | - | - | **50.0(152)** |
| 2020 | 0.0 (2) | - | - | - | - | - | **0.0 (2)** |

* Figures for 2009 are for July onwards only.

** The total for 2012 includes 8 daylight acoustic searches during seismic while drilling, where 87.5% were of adequate duration.

On surveys where PAM was available, on most occasions an adequate pre-shooting search was performed at dawn or dusk by either visual or acoustic monitoring or some combination of methods (Table 9). On the small number of occasions where there was not an adequate search at dawn, this was usually due either to PAM not being used (with no visual search) or PAM stopping too soon (with no visual search or stopping before visual observations began); together these accounted for 50% of inadequate searches at dawn. Similarly, when there was not an adequate search at dusk this was often (44% of occasions) due to PAM not being used (with no visual search) or PAM starting too late (with no visual search or starting after visual observations stopped).

**Table 9.** Percentage of adequate pre-shooting searches by visual and/or acoustic means at dawn or dusk within the UKCS when airguns were used between 2011 and 2020 (until 2013 this includes all surveys where PAM was used; from 2014 this includes all surveys where PAM was required at night as a condition of consent).

| Descriptor | Dawn | Dusk |
|---|---|---|
| Adequate search: | | |
| Visual | 24.7 | 29.0 |
| Acoustic | 43.2 | 32.4 |
| Both visual and acoustic | 13.2 | 17.4 |
| Overlapping visual and acoustic | 14.4 | 16.3 |
| Inadequate search | 4.5 | 4.9 |
| Sample size | 623 | 552 |

Where reasons were given for an inadequate pre-shooting search these included:

- misinterpretation of guideline or consent requirements for the duration of the search (including the MMO believing that a search was not required prior to testing a single airgun and searches not being carried out prior to use of a mini airgun)
- MMOs not being available (sometimes due to having a dual role and attending to other duties)
- insufficient staffing levels (including using one person to cover both MMO and PAM on VSPs)
- the MMO / PAM operator attending a safety drill
- lack of communication between crew and MMO / PAM operator (including the crew assuming an adequate search had been done and starting operations without checking)
- human error (including airguns being fired accidentally without warning)
- poor visibility
- using PAM as a substitute for (rather than complementary to) a visual search during daylight
- switching to PAM during increased sea states and stopping the visual search, even though there were enough personnel to cover both visual and PAM
- MMOs stopping the search to help deploy PAM
- difficulties deploying the PAM array (including weather conditions being too poor for deployment)

- failure of the PAM equipment due to technical problems or damage
- a delay in provision of PAM equipment (particularly spare equipment)
- restrictions on searching in Norwegian waters when the vessel was outside UK waters during the pre-shooting search period for a survey line that began within UK waters.

### 3.3.2 High resolution surveys

Standards of visual pre-shooting searches in most years were slightly lower when sources other than airguns were used (Table 10). PAM was less often a requirement of consent where only high-resolution sources were used; however, where it was required by consent, standards of acoustic pre-shooting searches were generally good at night. On the few occasions when PAM was required to complement the visual search during daylight, standards were poor (Table 10). There were few occasions when a pre-shooting search was needed at dawn or dusk on surveys when PAM was required during periods of darkness; these were mostly done by PAM with searches at dawn being of a lower standard than searches at dusk (Table 11).

**Table 10.** Percentage (and sample size) of adequate duration pre-shooting searches on high resolution surveys wholly within the UKCS when high resolution sources excluding airguns were used, from August 2017 onwards (for PAM includes only surveys where PAM was required at night or during the day as a condition of consent).

| Year | Visual search in daylight | Acoustic search at night | Acoustic search in daylight |
|---|---|---|---|
| 2017 | 80.0 (10) | 100.0 (7) | - |
| 2018 | 91.6 (285) | 89.2 (37) | 0.0 (1) |
| 2019 | 88.7 (444) | 92.1 (76) | 0.0 (7) |
| 2020 | 91.0 (78) | 100.0 (24) | 60.0 (5) |

**Table 11.** Percentage of adequate pre-shooting searches by visual and/or acoustic means at dawn or dusk within the UKCS when high resolution sources (without airguns) were used from August 2017 onwards (includes only surveys where PAM was required at night as a condition of consent).

| Descriptor | Dawn | Dusk |
|---|---|---|
| Adequate search: | | |
| Visual | 20.0 | 0.0 |
| Acoustic | 46.7 | 55.6 |
| Both visual and acoustic | 0.0 | 11.1 |
| Overlapping visual and acoustic | 13.3 | 33.3 |
| Inadequate search | 20.0 | 0.0 |
| Sample size | 15 | 9 |

Where searches on high resolution surveys did not meet the required standard, it was often because they ended prematurely; 45% of inadequate visual searches in daylight and 50% of inadequate acoustic searches at night ended before the start of the survey line. Sometimes searches were not conducted; one MMO report noted that due to miscommunication between the MMO and the surveyors the survey crew were unaware of the requirement for mitigation for sub-bottom profilers and a pre-shooting search therefore did not take place. Missing searches accounted for 37% of inadequate visual searches in daylight and 30% of

inadequate acoustic searches at night. A smaller proportion of inadequate searches were due to the search commencing late (22% of visual daylight searches and 20% of acoustic searches at night).

Where acoustic searches in daylight were inadequate, this was always due to acoustic monitoring not being undertaken. On 90% of occasions when there was no acoustic search in daylight on high resolution surveys there was only one PAM operator on board. Where the consent required that the visual search in daylight was supplemented with PAM, this was only done on three occasions on one survey in 2020; on this survey the contractor initially undertook acoustic monitoring in daylight in accordance with the consent, but the client then confirmed that this was not required, although a copy of the consent dated after the client's confirmation indicated that it was still a requirement. Nevertheless, the contractor ceased further daylight acoustic monitoring. There were no other occasions when PAM was used for pre-shooting searches in daylight on high resolution surveys.

## 3.4 Delays in operations

### 3.4.1 Surveys using airguns

Between 2011 and 2020 there were 158 occasions (including three occasions noted in MMO reports where data were missing) within the UKCS when firing was required to be delayed due to the presence of marine mammals within the mitigation zone (on surveys either wholly or partially within the UKCS but where the marine mammals were detected when within the UKCS). In comparison to the usage of airguns, the number of delays required was low (Table 12), with one delay required for every 194 uses (survey lines or tests) of the airguns over the 10-year period (= 0.5% occasions when airguns were used). Most delays (85%) were required prior to firing a survey line (without testing beforehand); 13% were required prior to testing conducted separately from a survey line and 3% were required prior to testing that led straight into a survey line. There was no evidence that delays were more prevalent on the first day when activity commenced on a survey compared to subsequent days ($\chi^2$ = 0.503, d.f. = 1, p > 0.05).

**Table 12.** Number and percentage of occasions when a delay in firing airguns was required within the UKCS (on surveys wholly within the UKCS).

| Year | Delays required | No. occasions when airguns were used | % occasions when a delay was required |
|---|---|---|---|
| 1998 | 11 | 1,989 | 0.6 |
| 1999 | 8 | 3,232 | 0.3 |
| 2000 | 9 | 2,546 | 0.4 |
| 2001 | 11 | 3,315 | 0.3 |
| 2002 | 14 | 2,969 | 0.5 |
| 2003 | 5 | 1,899 | 0.3 |
| 2004 | 5 | 1,836 | 0.3 |
| 2005 | 9 | 2,992 | 0.3 |
| 2006 | 30 | 3,071 | 1.0 |
| 2007 | 12 | 2,557 | 0.5 |
| 2008 | 17 | 2,364 | 0.7 |
| 2009 | 4 | 1,904 | 0.2 |

| Year | Delays required | No. occasions when airguns were used | % occasions when a delay was required |
|---|---|---|---|
| 2010 | 19 | 2,712 | 0.7 |
| 2011 | 16 * | 5,355 | 0.3 |
| 2012 | 13 | 5,032 | 0.3 |
| 2013 | 28 | 5,506 | 0.5 |
| 2014 | 13 * | 3,003 | 0.4 |
| 2015 | 13 | 1,870 | 0.7 |
| 2016 | 29 | 2,344 | 1.2 |
| 2017 | 16 * | 2,078 | 0.8 |
| 2018 | 7 | 2,200 | 0.3 |
| 2019 | 11 | 1,313 | 0.8 |
| 2020 | 3 | 275 | 1.1 |

* In addition, there were three occasions in 2011, one in 2014 and one in 2017 when marine mammals were detected prior to operations commencing but there was no delay; however, for all occasions there was insufficient detail regarding the timing and/or distance of the animals to determine whether they were in the mitigation zone in the 20 minutes before firing commenced. Also, there were two occasions in 2011 and one in 2014 where delays were noted in the MMO reports but the recording forms were missing; as detailed information is not available these instances are not included in the table, but the reports indicate that delays were implemented.

Delays were required most often due to the presence of white-beaked dolphins, unidentified dolphins, minke whales or common dolphins in the mitigation zone. Collectively, dolphins accounted for 54% of delays. Delays resulted from visual detections on 76% of occasions, acoustic detections on 19% of occasions and for animals detected by both means on 5% of occasions. Of note was one survey in the South-west Approaches, St George's Channel and western part of the English Channel where there were many sightings and acoustic detections, particularly of dolphins (common dolphins where identified) that were often bow-riding, resulting in 16 occasions when the soft start had to be delayed (correct procedures were followed on all but one of these occasions).

On most occasions between 2011 and 2020 when a delay was required the correct procedures were followed. During this period, compliance improved from 2013 onwards, although with a slight decline in standards in 2017 (Table 13). When the correct procedures were not followed, this was usually due to there being no delay or the delay being too short (mostly there was no delay). On four occasions the subsequent soft start was too short.

Between 2011 and 2020 there were five additional occasions (not counted in the tables but amongst those noted in the footnote to Table 12) where marine mammals were detected during the pre-shooting search and firing began within 20 minutes of the detection without a delay. There was insufficient detail regarding the timing and/or distance to determine whether the animals were in the mitigation zone prior to firing or not, but no reason was given for not delaying. Four of these were acoustic detections where no range was given; the fifth was a visual detection noted to be in the mitigation zone but the time when it left the mitigation zone was not recorded. There was no record that the MMO or PAM operator requested a delay for any of these detections.

**Table 13.** Number and percentage of occasions when correct / incorrect procedures were followed when a delay in firing airguns was required within the UKCS (on surveys either wholly or partially within the UKCS but where the marine mammals were detected when within the UKCS).

| Year | Correct procedures followed | No attempt to delay firing | Delay of < 20 mins before firing commenced | Subsequent soft start too short | Both delay and subsequent soft start too short * | Number of delays required |
|---|---|---|---|---|---|---|
| 1997* | ≥1(≥25.0%) | 0 (0.0%) | ? | ? | ? | 4 |
| 1998 | 2 (18.2%) | 2 (18.2%) | 2(18.2%) | 7 (63.6%) | 2 (18.2%) | 11 |
| 1999 | 1 (12.5%) | 3 (37.5%) | 1(12.5%) | 5 (62.5%) | 2 (25.0%) | 8 |
| 2000 | 7 (77.8%) | 1 (11.1%) | 0 (0.0%) | 1 (11.1%) | 0 (0.0%) | 9 |
| 2001 | 4 (36.4%) | 3 (27.3%) | 2(18.2%) | 3 (27.3%) | 1 (9.1%) | 11 |
| 2002 | 11 (73.3%) | 2 (13.3%) | 0 (0.0%) | 3 (20.0%) | 1 (6.7%) | 15 |
| 2003 | 3 (60.0%) | 1 (20.0%) | 0 (0.0%) | 2 (40.0%) | 1 (20.0%) | 5 |
| 2004 | 7 (87.5%) | 1 (12.5%) | 0 (0.0%) | 1 (12.5%) | 1 (12.5%) | 8 |
| 2005 | 2 (22.2%) | 4 (44.4%) | 1(11.1%) | 3 (33.3%) | 1 (11.1%) | 9 |
| 2006 | 17 (54.8%) | 8 (25.8%) | 4(12.9%) | 4 (12.9%) | 2 (6.5%) | 31 |
| 2007 | 9 (64.3%) | 3 (21.4%) | 1 (7.1%) | 1 (7.1%) | 0 (0.0%) | 14 |
| 2008 | 15 (88.2%) | 0 (0.0%) | 1 (5.9%) | 2 (11.8%) | 1 (5.9%) | 17 |
| 2009 | 3 (75.0%) | 0 (0.0%) | 0 (0.0%) | 1 (25.0%) | 0 (0.0%) | 4 |
| 2010 | 15 (78.9%) | 2 (10.5%) | 2(10.5%) | 0 (0.0%) | 0 (0.0%) | 19 |
| 2011** | ≥12(≥70.6%) | 2 (11.8%) | 1 (5.9%) | 1 (5.9%) | 0 (0.0%) | 17 |
| 2012 | 10 (76.9%) | 2 (15.4%) | 1 (7.7%) | 1 (7.7%) | 1 (7.7%) | 13 |
| 2013 | 26 (92.9%) | 1 (3.6%) | 0 (0.0%) | 1 (3.6%) | 0 (0.0%) | 28 |
| 2014 | 14 (93.3%) | 1 (6.7%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 15 |
| 2015 | 13 (92.9%) | 0 (0.0%) | 1 (7.1%) | 0 (0.0%) | 0 (0.0%) | 14 |
| 2016 | 28 (93.3%) | 1 (3.3%) | 0 (0.0%) | 1 (3.3%) | 0 (0.0%) | 30 |

| Year | Correct procedures followed | No attempt to delay firing | Delay of < 20 mins before firing commenced | Subsequent soft start too short | Both delay and subsequent soft start too short * | Number of delays required |
|---|---|---|---|---|---|---|
| 2017 | 14 (87.5%) | 2 (12.5%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 16 |
| 2018 | 7(100.0%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 7 |
| 2019 | 11 (91.7%) | 1 (8.3%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 12 |
| 2020 | 3(100.0%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 3 |

* Occasions where both the delay and subsequent soft start were too short are also included in the other relevant columns

** Of four delays in 1997 it is known that one followed correct procedures, but as operations data was not recorded in 1997 it is not known whether the length of delay or subsequent soft start was long enough on the other three occasions; on one occasion in 2011 from the information recorded it was not clear whether the delay was long enough.

On most occasions when correct procedures were not followed there was no apparent explanation. However, a few reasons were noted in reports or were evident from the data:

- the MMO thinking the airguns were already firing
- the MMO being unaware of plans to test the equipment
- the MMO not noticing until later that the sighting was at a time when operations were about to commence
- the MMO / crew believing that shortening the soft start after delaying was “necessary” and “allowed”.

There was one VSP operation where, following discussion with JNCC, firing was allowed to commence with seals in the mitigation zone. In this instance JNCC allowed longer soft starts (over 40 minutes) to commence due to 10 seals having taken up residence on the platform. The report noted that seals were visible at the surface during the first five minutes of the soft start, but the lack of sightings thereafter suggested they had moved away, although the data recorded lacked detail. The report also said that ‘mitigation shots’ were fired every nine minutes to prevent the seals returning to the mitigation zone, although there is no record that this was agreed with JNCC. The seals were reported as returning to the area after the source stopped and were also seen the following day.

There was one occasion on a 4D survey when two common dolphins (an adult and juvenile pair) entered the mitigation zone and were observed there continuously during daylight hours for the remainder of the survey. The report recorded several attempts made to lure the dolphins away or deter them from the vicinity of the vessel: the crew on the support vessel threw fish into the sea, a workboat towed buoys on a line, loud music and recorded whale sounds were played from the helideck and the “captain fired several flares into the sea close to the dolphins, in an attempt to frighten them away”. The report does not record whether the MMOs or PAM operator advised the crew against this. Advice was sought from JNCC and BEIS, although they were not informed that flares had been fired. The report said that following advice from JNCC the vessel moved to an area with higher fish aggregations in the hope that the dolphins would remain there. None of the attempts to lure away / deter the dolphins worked and the dolphins remained in the vicinity of the vessel, visible during daylight. Permission was sought from BEIS to resume shooting during daylight despite the dolphins’ presence but following full consideration of the circumstances, BEIS confirmed that the mitigation requirements in the consent remained. As the dolphins were not being detected acoustically, operations were delayed until night-time with no new lines commencing during the day when the dolphins could be visually detected. Therefore, the remaining six survey lines and one test commenced after dark, prolonging the survey by four days beyond the predicted end time. The MMO report noted that, although it seemed probable that the dolphins were present during hours of darkness, as they could not be seen after dark and were not detected acoustically “no non-compliance with JNCC guidelines occurred”.

On this survey there were no acoustic detections of marine mammals at any time. The report stated that the PAM equipment was functioning correctly and was picking up clear signals of the gun signatures, echo sounder pings and rattling chains on the guns. It was deployed at a depth below the draft of the vessel, so considered capable of detecting animals ahead on the bow of the vessel. The report speculated on possible reasons for the lack of detection of the dolphins: the animals not vocalising, or their orientation being mainly away from the PAM array, or masking by the noise of the vessel’s propeller and its wash, or inadequate sensitivity of the hydrophones. There was no record in the report or in the data of the PAM array being deployed during the day when the dolphins’ presence was confirmed

visually to assess its efficacy at detecting them and therefore potentially increase confidence regarding their absence when they were not detected at night.

There were also some occasions when crews voluntarily acted beyond the requirements of the JNCC guidelines in delaying operations due to the presence of marine mammals. On one VSP a test was terminated when a seal appeared close to the airguns partway through the test. On another VSP the decision was made to abort a soft start that was already underway when dolphins came into the mitigation zone; operations were subsequently delayed for 38 minutes to allow safe passage of the dolphins. On one site survey a test was delayed for over four hours "until much later in the day" due to killer whales that were slightly outside the mitigation zone (525 m from the airguns).

### 3.4.2 High resolution surveys

Between August 2017 and 2020 there were 15 occasions within the UKCS when use of high-resolution sources was required to be delayed due to the presence of marine mammals within the mitigation zone (on surveys either wholly or partially within the UKCS but where the marine mammals were detected when within the UKCS). In addition, there were 16 occasions where the use of high-resolution sources was delayed between 2014 and August 2017, prior to the inclusion of these sources in the JNCC guidelines. The number of occasions when high resolution sources (without airguns) were used was low when compared to the use of airguns and the proportion of occasions when a delay was required / enacted was more variable (Table 14). Although infrequent, delays with high resolution sources occurred relatively more often compared to usage of the source than with airguns; during the three full years (2018–2020) since they were included in the JNCC guidelines, one delay was required for every 104 uses of high-resolution sources (= 1.0% of occasions when sources were used). Delays were required more often prior to firing a survey line (73%) than prior to testing (27%). Sample sizes were insufficient to test whether delays were more prevalent at the start of a survey.

**Table 14.** Number and percentage of occasions when a delay in the use of high-resolution sources (without airguns) was required or enacted within the UKCS (on surveys wholly within the UKCS).

| Year | Delays enacted / required | No. occasions when sources were used | % occasions when a delay was enacted / required |
|---|---|---|---|
| 2014 | 3 | 369 | 0.8 |
| 2015 | 10 | 300 | 3.3 |
| 2016 | 0 | 209 | 0.0 |
| 2017 pre-August | 3 | 125 | 2.4 |
| 2017 August onwards | 0 | 33 | 0.0 |
| 2018 | 8 | 461 | 1.7 |
| 2019 | 6 | 943 | 0.6 |
| 2020 | 1 | 162 | 0.6 |

A range of species caused delays with high resolution sources (without airguns), but considering all delays required or enacted since 2014, grey seals or unidentified seals accounted for 45% of instances. All delays except one resulted from visual detections; there was one delay in 2019 due to an acoustic detection.

In 2018 and 2019, subsequent to the inclusion of high-resolution sources in the JNCC guidelines, the proportion of occasions when correct procedures were followed when a delay in operations was required was lower than that for airguns (Table 15), although sample sizes were also low. On the single occasion when a delay was required in 2020, the correct procedures were followed. When correct procedures were not followed in 2018 and 2019 it was mostly due to there being no soft start following the delay. On all three occasions when this happened, the MMO report said that a soft start was not possible with the equipment, but the consents required a soft start and there was no record of any discussions with JNCC or BEIS regarding difficulties of complying with this requirement.

**Table 15.** Number and percentage of occasions when correct / incorrect procedures were followed when a delay in use of high-resolution sources (without airguns) was required within the UKCS since August 2017 (on surveys either wholly or partially within the UKCS but where the marine mammals were detected when within the UKCS).

| Year | Correct procedures followed | No attempt to delay operations | Delay of < 20 mins before operations commenced | Subsequent soft start too short | Both delay and subsequent soft start too short* | Number of delays required |
|---|---|---|---|---|---|---|
| 2017 | - | - | - | - | - | - |
| 2018 | 5 (62.5%) | 1 (12.5%) | 0 (0.0%) | 2 (25.0%) | 0 (0.0%) | 8 |
| 2019 | 5 (83.3%) | 0 (0.0%) | 0 (0.0%) | 1 (16.7%) | 0 (0.0%) | 6 |
| 2020 | 1 (100.0%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 1 |

* Occasions where both the delay and subsequent soft start were too short are also included in the other relevant columns.

In addition to these delays, there was one occasion on a high-resolution survey in 2017 (prior to the inclusion of high resolution surveys in the guidelines in August) where the soft start of a chirp was aborted because a minke whale came into the mitigation zone.

## 3.5 The soft start

### 3.5.1 Surveys using airguns

Many surveys with airguns performed a soft start by increasing the number of airguns firing or increasing the frequency of shots (Figure 2). Increasing the pressure was used least often. Of those surveys using the increasing pressure method (on its own or in combination with increasing the number of airguns) 92% had array volumes of 1,000 cu.in. or less and 87% were VSPs. Of those surveys using the increasing firing frequency method (on its own or in combination with increasing the number of airguns) 96% were site surveys and had array volumes of 180 cu.in. or less. Although the proportion of surveys using the increasing frequency method declined since August 2017, one-third of surveys were still using this method (Figure 2); in 2020 all site surveys with airgun volumes below 180 cu.in. used this method of soft start.

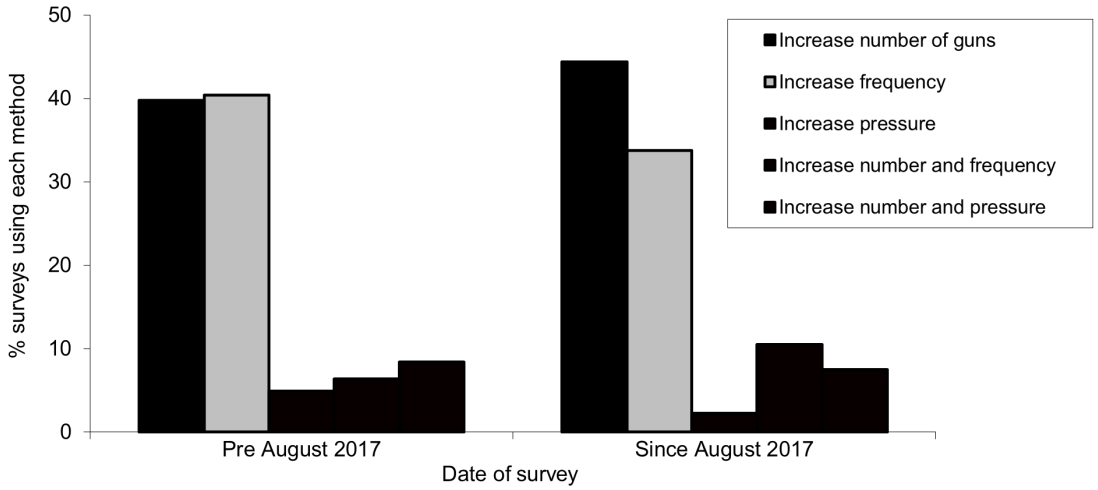


**Figure 2.** Method of soft start used for airguns between 2011 and 2020.

The majority of soft starts of airguns between 2011 and 2020 met the required minimum duration (Table 16). There was a drop in standards on site surveys in 2013, but standards overall were consistently high since 2014. In the August 2017 revision of the JNCC guidelines, the minimum soft start duration for airgun arrays with volumes up to 180 cu.in. was reduced to 15 minutes – since then only two soft starts on site surveys have been shorter than the required minimum duration.

**Table 16.** Percentage (and sample size) of airgun soft starts within the UKCS lasting the required minimum duration from the commencement of the soft start until full power (excluding test firing and the use of a single mini airgun). Prior to August 2017 the required minimum duration was 20 minutes; from August 2017 onwards, the required minimum duration was 20 minutes for airgun arrays greater than 180 cu.in. and 15 minutes for smaller arrays.

| Year | Site | VSP | 2D | 3D | 4D | OBS | Total |
|---|---|---|---|---|---|---|---|
| 2003 | 0.3 (767) | 83.3 (6) | 85.5(152) | 90.6(542) | 92.8(195) | 97.0(164) | **53.0(1,826)** |
| 2004 | 22.8 (906) | 75.0 (12) | 100.0 (26) | 99.8(415) | 99.7(307) | 100.0 (43) | **58.8(1,709)** |
| 2005 | 44.8 (976) | 40.0 (5) | 91.9(347) | 92.0(887) | 94.3(634) | - | **76.2(2,849)** |
| 2006 | 74.3 (913) | 85.7 (14) | 62.0(279) | 97.3(1,007) | 74.5(526) | 90.1 (71) | **81.8(2,810)** |
| 2007 | 73.6 (537) | 82.6 (23) | 98.7(390) | 83.6(487) | 68.1(736) | 100.0 (9) | **78.6(2,182)** |
| 2008 | 86.2 (515) | 100.0(12) | 94.3(174) | 98.5(949) | 96.3(434) | 85.2 (27) | **94.6(2,111)** |
| 2009 | 79.2 (586) | 95.8 (24) | 100.0 (73) | 99.5(418) | 97.4(232) | 98.8(166) | **91.1(1,499)** |
| 2010 | 88.2 (490) | 94.7 (19) | 94.3 (35) | 98.9(635) | 98.2(453) | 95.1(184) | **95.3(1,816)** |
| 2011 | 88.7 (839) | 100.0(22) | 95.8 (95) | 98.6(935) | 100.0(172) | 97.5(1,428) | **95.8(3,491)** |
| 2012 | 97.1(1,067) | 90.6 (32) | - | 98.6(1,463) | 99.5(385) | 97.2(1,068) | **97.8(4,041*)** |
| 2013 | 76.3(1,440) | 90.9 (22) | 100.0 (87) | 99.4(1,694) | 99.9(717) | 87.5 (8) | **91.1(3,968)** |
| 2014 | 96.6 (862) | 95.2 (21) | 96.6 (58) | 98.3(462) | 100.0 (93) | 100.0(846) | **98.3(2,342)** |
| 2015 | 97.4 (723) | 100.0(18) | 100.0 (10) | 100.0(337) | 100.0 (9) | 99.8(517) | **98.8(1,614)** |
| 2016 | 98.9 (878) | 100.0 (4) | 98.9(182) | 100.0(124) | 99.2(127) | 99.8(595) | **99.3(1,910)** |
| 2017 | 97.8 (412) | 92.3 (13) | 99.0(105) | 100.0 (67) | 97.1 (69) | 99.7(1,085) | **99.1(1,751)** |
| 2018 | 100.0(443) | 100.0 (5) | 100.0 (12) | 100.0(550) | 98.2(225) | 99.6(543) | **99.7(1,778)** |
| 2019 | 99.8 (613) | 100.0(80) | 100.0 (1) | 99.3(437) | 100.0 (12) | - | **99.7(1,143)** |
| 2020 | 99.5 (185) | - | - | - | 100.0 (35) | - | **99.5 (220)** |

* The total for 2012 includes 26 soft starts during seismic while drilling, where 100% were at least 20 minutes until full power was reached.

In the initial years of the 2011–2020 period there were some occasions when there was no soft start (Table 17). This was particularly the case for site surveys in 2013, accounting for many of the occasions when the soft start did not meet the minimum duration on these surveys. Many of these occasions were when small airguns were used, and crews regarded these as mini-airguns and therefore believed they were exempt from having to do a soft start. However, the JNCC guidelines define a mini airgun as a single airgun with a maximum volume of 10 cu.in.; although a single airgun with a volume of 12 cu.in. has also been regarded as a mini-airgun for the purposes of this analysis, surveys utilising two mini-airguns firing together have not been treated as being exempt from the requirement for a soft start. Some reports claimed that an exemption from conducting a soft start had been agreed for two mini-airguns, but no documentary evidence of this was provided. All but five of the occasions when there was no soft start on site surveys in 2013 occurred on surveys with airgun volumes of 20 cu.in. (two 10 cu.in. airguns) or 24 cu.in. (two 12 cu.in. airguns). Since 2014 there have been very few occasions when the soft start was omitted.

Where the time of start of line was recorded, this was mostly within the maximum permitted duration of the soft start, although prolonged soft starts sometimes happened on VSPs (Table 18). From 2017 onwards there was also an increased proportion of soft starts on site surveys that exceeded the maximum permitted duration. When the JNCC guidelines were revised in August 2017, as well as reducing the minimum required duration for soft starts of airgun arrays with volumes up to 180 cu.in., the maximum permitted duration was also reduced from 40 minutes to 25 minutes. Although there was almost 100% compliance with the revised minimum duration this was not the case for the maximum duration; several soft starts of small arrays exceeded 25 minutes from commencement until the start of line. All but one of the non-compliances with the maximum soft start duration on site surveys in 2017 occurred after the guideline revision in August. It seemed that crews were still applying the previous maximum duration as on all occasions since then the time from commencement of the soft start until the start of line was within 40 minutes. In 2019 and 2020 there was a progressive reduction in the number of excessively long soft starts on site surveys, although standards had not yet improved to reach the level of the preceding years.

**Table 17.** Percentage (and sample size) of occasions when there was no soft start of airguns within the UKCS (excluding test firing and the use of a single mini airgun).

| Year | Site | VSP | 2D | 3D | 4D | OBS | Total |
|---|---|---|---|---|---|---|---|
| 2003 | 62.6 (767) | 16.7 (6) | 0.0 (152) | 0.2 (542) | 0.0 (195) | 0.0 (164) | **26.4(1,826)** |
| 2004 | 60.5 (906) | 16.7 (12) | 0.0 (26) | 0.0 (415) | 0.0 (307) | 0.0 (43) | **32.2(1,709)** |
| 2005 | 1.9 (976) | 0.0 (5) | 0.0 (347) | 5.3 (887) | 0.5 (634) | - | **2.4 (2,849)** |
| 2006 | 0.8 (913) | 0.0 (14) | 0.0 (279) | 0.2(1,007) | 0.2 (526) | 0.0 (71) | **0.4 (2,810)** |
| 2007 | 8.6 (537) | 8.7 (23) | 0.3 (390) | 0.8 (487) | 0.0 (736) | 0.0 (9) | **2.4 (2,182)** |
| 2008 | 3.7 (515) | 0.0 (12) | 0.0 (174) | 0.2 (949) | 0.0 (434) | 3.7 (27) | **0.8 (2,111)** |
| 2009 | 13.8 (586) | 0.0 (24) | 0.0 (73) | 0.0 (418) | 0.4 (232) | 0.0 (166) | **5.5 (1,499)** |
| 2010 | 0.2 (490) | 5.3 (19) | 2.9 (35) | 0.0 (635) | 0.4 (453) | 0.5 (184) | **0.3 (1,816)** |
| 2011 | 7.9 (839) | 0.0 (22) | 1.1 (95) | 0.3 (935) | 0.0 (172) | 0.31,428) | **2.1 (3,491)** |
| 2012 | 0.9(1,067) | 0.0 (32) | - | 0.1(1,463) | 0.3 (385) | 0.6(1,068) | **0.4(4,041*)** |
| 2013 | 21.3(1,440) | 4.5 (22) | 0.0 (87) | 0.0(1,694) | 0.0 (717) | 12.5 (8) | **7.8 (3,968)** |
| 2014 | 1.3 (862) | 0.0 (21) | 0.0 (58) | 0.0 (462) | 0.0 (93) | 0.0 (846) | **0.5 (2,342)** |
| 2015 | 0.6 (723) | 0.0 (18) | 0.0 (10) | 0.0 (337) | 0.0 (9) | 0.0 (517) | **0.2 (1,614)** |
| 2016 | 0.0 (877) | 0.0 (4) | 0.0 (182) | 0.0 (124) | 0.0 (127) | 0.0 (595) | **0.0 (1,910)** |
| 2017 | 0.2 (412) | 7.6 (13) | 0.0 (105) | 0.0 (67) | 0.0 (69) | 0.0(1,085) | **0.1 (1,751)** |
| 2018 | 0.0 (443) | 0.0 (5) | 0.0 (12) | 0.0 (550) | 0.0 (225) | 0.2 (543) | **0.1 (1,778)** |
| 2019 | 0.2 (613) | 0.0 (80) | 0.0 (1) | 0.2 (437) | 0.0 (12) | - | **0.2 (1,143)** |
| 2020 | 0.0 (185) | - | - | - | 0.0 (35) | - | **0.0 (220)** |

* The total for 2012 includes 26 soft starts during seismic while drilling, where there were no occasions when there was no soft start.

**Table 18.** Percentage (and sample size) of occasions when the time from the beginning of the soft start of airguns until the start of line exceeded the maximum permitted duration within the UKCS (excluding test firing and the use of a single mini airgun). Prior to August 2017 the required maximum duration was 40 minutes; from August 2017 onwards, the required maximum duration was 40 minutes for airgun arrays greater than 180 cu.in. and 25 minutes for smaller arrays.

| Year | Site | VSP | 2D | 3D | 4D | OBS | Total |
|---|---|---|---|---|---|---|---|
| 2005 | 0.6 (469) | - | 4.4 (91) | - | - | - | **1.3 (560)** |
| 2006 | 2.9 (748) | - | 9.2(218) | 14.8(236) | - | 22.4 (67) | **7.2(1,269)** |
| 2007 | 4.6 (370) | 0.0 (3) | 13.1(259) | 5.1(369) | 44.1(272) | - | **14.9(1,273)** |
| 2008 | 10.0 (488) | 40.0 (5) | 9.8 (41) | 9.2(272) | 23.3(172) | 0.0 (5) | **12.2 (983)** |
| 2009 | 5.7 (458) | 38.1 (21) | 31.4 (70) | 13.5(401) | 5.6(231) | 11.7 (162) | **10.6(1,343)** |
| 2010 | 1.7 (479) | 30.8 (13) | 17.6 (34) | 3.0(632) | 11.5(435) | 8.3 (181) | **5.7(1,774)** |
| 2011 | 3.1 (703) | 22.2 (18) | 0.0 (93) | 7.1(930) | 23.3(163) | 1.1(1,413) | **4.4(3,320)** |
| 2012 | 1.3(1,046) | 7.1 (28) | - | 6.5(1,452) | 4.5(380) | 1.7(1,037) | **3.7(3,943)** |
| 2013 | 0.8(1,111) | 0.0 (16) | 11.4 (88) | 2.6(1,678) | 4.7(709) | 0.0 (6) | **2.6(3,608)** |
| 2014 | 0.0 (845) | 0.0 (11) | 1.7 (58) | 4.4(455) | 3.3 (92) | 0.1 (822) | **1.1(2,283)** |
| 2015 | 0.4 (714) | 0.0 (9) | 0.0 (10) | 1.5(336) | 44.4 (9) | 0.0 (505) | **0.8(1,583)** |
| 2016 | 0.3 (865) | 50.0 (4) | 7.0(172) | 0.8(123) | 2.4(127) | 0.9 (563) | **1.4(1,854)** |
| 2017 | 26.2 (408) | 12.5 (8) | 2.9(103) | 0.0 (67) | 0.0 (68) | 0.3(1,044) | **6.7(1,698)** |
| 2018 | 25.5 (440) | 40.0 (5) | 0.0 (12) | 0.9(550) | 0.5(215) | 0.4 (535) | **6.9(1,757)** |
| 2019 | 14.1 (612) | 6.8 (73) | 0.0 (1) | 2.3(434) | 0.0 (12) | - | **8.9(1,132)** |
| 2020 | 6.5 (184) | - | - | - | 0.0 (35) | - | **5.5 (219)** |

Although most soft starts were of adequate duration, where reasons were given for them being either short or prolonged, the most common reasons included:

- variations in vessel speed due to currents or tides
- other vessels or fishing gear being present during line changes necessitating a change in course or speed
- human error (e.g. miscalculation by surveyors, trainee operator starting at full power);
- the crew not adhering to guidelines when the MMO was off duty (e.g. at night);
- communication problems between crew or between crew and mitigation personnel
- change of plan during the line change
- technical issues on the approach to line (e.g. with gun controllers, compressors, navigation systems, recording equipment, streamer positioning)
- problems with airgun deployment
- issues during undershooting
- restrictions during time-sharing
- applying the exemption for a single mini airgun of maximum 10 cu.in. to an array comprising two 10 cu.in. or two 12 cu.in. mini airguns
- line changes taking longer than expected so airguns that initially continued to fire were then stopped but there was insufficient time remaining for a full soft start
- not being ready for the start of line at the end of a soft start on VSPs
- there not being enough time for a full soft start between entering the greater working area and the start of line (some soft starts commenced outside the greater working area to meet the required duration)
- misunderstanding of the requirements of the guidelines for small airgun arrays following the August 2017 revision
- the MMO forgetting the changed requirements for small airgun arrays following the August 2017 revision of guidelines.

On 2D, 3D, 4D and OBS surveys where MMO reports included details of the progression of soft starts, spare airguns were often recorded as being used in the soft start in addition to the other airguns, resulting in the maximum volume exceeding the specified production volume (Table 19). The surveys where this happened in 2011–2020 were mostly operated by the same two seismic exploration companies. However, in recent years it has become very rare for MMOs to provide details of the progression of soft starts on surveys with large arrays of airguns, so the extent of the problem amongst other operators is unknown. It is much more common for MMOs on site surveys to detail the progression of soft starts, but these surveys have smaller arrays that do not include spare airguns, so it is impossible for them to exceed production volume during the soft start. In addition to the surveys included in Table 18 there were also two OBS surveys in 2014 where the soft start exceeded production volume for some, but not all, survey lines. The normal production volumes were 5110 cu.in. and 2950 cu.in. but some lines were completed using only 500 cu.in. / 800 cu.in. respectively, rather than doing a soft start up to 500 / 800 cu.in. it appeared that a soft start up to 5110 / 2950 cu.in. was undertaken and then the volume reduced to 500 / 800 cu.in.

**Table 19.** Increase in volume of airguns firing during the soft start above production volume (2D, 3D, 4D and OBS surveys only).

| Year | % surveys where soft start volume exceeded production volume | Mean % increase | Maximum % increase | Sample size |
|---|---|---|---|---|
| 2009 | 60.0 | 25.2 | 48.9 | 5 |
| 2010 | 60.0 | 24.0 | 76.6 | 10 |
| 2011 | 50.0 | 22.9 | 76.6 | 14 |
| 2012 | 62.5 | 18.2 | 28.1 | 16 |
| 2013 | 83.3 | 13.1 | 16.0 | 6 |
| 2014 | 83.3 | 12.1 | 12.1 | 6 |
| 2015 | - | - | - | 0 |
| 2016 | - | - | - | 0 |
| 2017 | 100.0 | 12.1 | 12.1 | 1 |
| 2018 | - | - | - | 0 |
| 2019 | - | - | - | 0 |
| 2020 | - | - | - | 0 |

### 3.5.2 High resolution surveys

Where a soft start was performed for high resolution sources the method was recorded as either increasing the frequency (i.e. the repetition rate) or 'other'; where specified this was by increasing the power output, occasionally accompanied by an increase in repetition rate. All three of the more commonly used sources (chirp, pinger and sparker) used the increasing power method more often than increasing the repetition rate, particularly in the case of pingers (Figure 3).

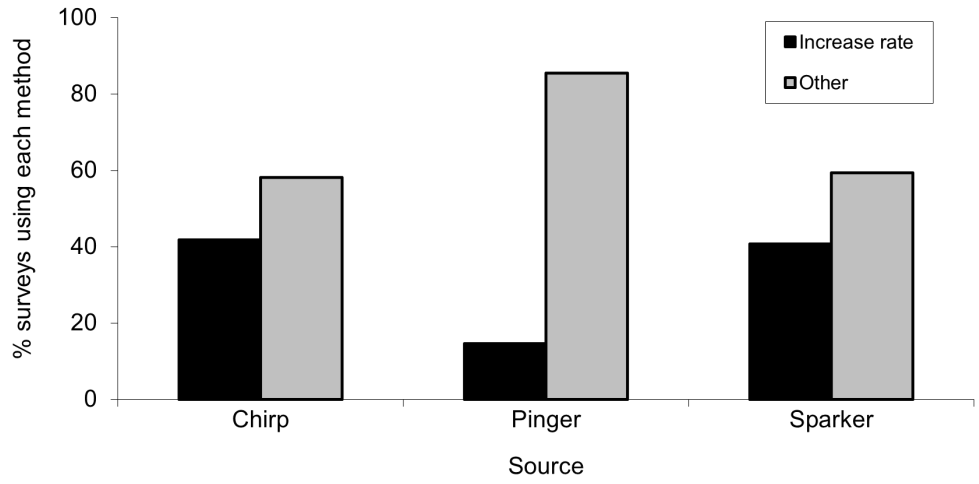


**Figure 3.** Method of soft start for high resolution sources between August 2017 and 2020 (only shows sources where method was recorded for more than 10 surveys; 'other' was usually by increasing the power output).

Compliance with the requirement to commence activity with a soft start was poor for high resolution surveys, with a substantial proportion not meeting the required minimum duration, although this did improve in 2020 (Table 20). On many occasions where the soft start did not meet the required minimum duration this was because there was no soft start. However, where there was a soft start, it was rare that the soft start was unduly prolonged.

**Table 20.** Compliance (and sample size) of soft starts of high resolution sources (without airguns) within the UKCS from August 2017 onwards (excluding testing; only surveys where the consent required a soft start to be implemented).

| Year | % where soft start to full power was minimum 20 minutes | % where soft start to start of line exceeded 40 minutes | % where no soft start |
|---|---|---|---|
| 2017 | 50.0 (8) | 0.0 (5) | 37.5 (8) |
| 2018 | 48.7 (117) | 1.3 (79) | 31.6 (117) |
| 2019 | 57.5 (504) | 0.0 (224) | 41.5 (504) |
| 2020 | 91.6 (95) | 0.0 (86) | 8.4 (95) |

Where reasons were given for not performing a soft start with high resolution sources, these included:

- unfamiliarity with the current guidelines
- a soft start could not be carried out with the equipment as power could not be varied
- adjusting power levels risked damaging the equipment.

## 3.6 Breaks in operations

### 3.6.1 Surveys using airguns

In 2011–2020 there were a total of 1,477 occasions when firing recommenced without a full soft start after a short break in firing of up to 10 minutes (Table 21). Although many of the breaks were for events that might be classed as planned, these all occurred prior to the 2017 guideline revision. Planned events accounted for 1,296 of the breaks, with 1,033 occurring during short line changes when the airguns could have continued firing (although 1,019 of these occasions took place on OBS surveys where there were agreements with JNCC that the airguns could be stopped for less than 10 minutes during line changes followed by a short soft start). Other short breaks that could be considered planned included stopping for sound checks and changing between stations on a VSP. Of the 181 occasions between 2011 and 2020 where the break might be classed as unplanned, 113 were due to tests being needed shortly after firing had stopped (either after a survey line or after a previous test). On many occasions there was adequate monitoring (Table 21); in the years where standards were lower this was often due to a lack of monitoring with PAM when the break occurred at night.

**Table 21.** Short breaks in firing of up to 10 minutes where the airguns resumed without a full soft start in the UKCS.

| Year | Number of short breaks | Mean duration (mins) | Maximum duration (mins) | % occasions when there was adequate monitoring prior to firing resuming |
|---|---|---|---|---|
| 2003 | 1 | 5 | 5 | 0.0 |
| 2004 | 0 | - | - | - |
| 2005 | 4 | 2 | 4 | 100.0 |
| 2006 | 1 | < 1 | < 1 | 100.0 |
| 2007 | 1 | 4 | 4 | 100.0 |
| 2008 | 2 | 2 | 3 | 100.0 |
| 2009 | 2 | 4 | 4 | 50.0 |
| 2010 | 86 | 5 | 10 | 39.5 |
| 2011 | 1,102 | 4 | 10 | 72.4 |
| 2012 | 15 | 7 | 9 | 60.0 |
| 2013 | 255 | 7 | 10 | 79.2 |
| 2014 | 10 | 6 | 10 | 90.0 |
| 2015 | 10 | 4 | 9 | 90.0 |
| 2016 | 27 | 4 | 10 | 88.9 |
| 2017 | 11 | 3 | 10 | 100.0 |
| 2018 | 21 | 3 | 10 | 100.0 |
| 2019 | 9 | 4 | 9 | 33.3 |
| 2020 | 17 | 4 | 10 | 100.0 |

### 3.6.2 High resolution surveys

Where high resolution sources were used without airguns, there were 201 occasions since August 2017 where there were short breaks in activity of up to 10 minutes and the source restarted without a soft start. In 2019 there were 191 breaks that would be classed as planned, occurring during short line changes when the source could have continued to be active (190 being on one survey), but there was no monitoring during these breaks, resulting in a very low standard of compliance with this aspect of the JNCC guidelines in that year (Table 22). Most of these breaks occurred during daylight when visual monitoring would have been possible.

**Table 22.** Short breaks in firing of up to 10 minutes where high-resolution sources resumed without a soft start in the UKCS, from August 2017 onwards.

| Year | Number of short breaks | Mean duration (mins) | Maximum duration (mins) | % occasions when there was adequate monitoring prior to operations resuming |
|---|---|---|---|---|
| 2017 | 0 | - | - | - |
| 2018 | 0 | - | - | - |
| 2019 | 197 | 5 | 10 | 1.5 |
| 2020 | 4 | 3 | 4 | 100.0 |

## 3.7 Source testing

### 3.7.1 Surveys using airguns

There were many occasions when the airguns were tested during surveys, with the total for each survey type reflecting the average number of tests and the number of surveys of that type. Site surveys and VSP generally had few tests per survey (Table 23). The highest number of tests between 2011 and 2020 occurred on 3D surveys, although OBS surveys had a higher mean number of tests per survey in some years. Of note was one 3D survey in 2014 where 193 of 349 occasions when airguns were used were purely for testing.

**Table 23.** Mean number of airgun tests per survey (and total per year) within the UKCS, by type of survey.

| Year | Site | VSP | 2D | 3D | 4D | OBS |
|---|---|---|---|---|---|---|
| 2005 | 2 (18) | - | 5 (22) | 4 (25) | 7 (7) | - |
| 2006 | 1 (13) | - | 10 (113) | 17 (69) | 24 (24) | 3 (3) |
| 2007 | 2 (49) | - | 13 (94) | 8 (46) | 19 (37) | 1 (1) |
| 2008 | 2 (62) | 1 (1) | 5 (23) | 8 (59) | 7 (26) | 8 (16) |
| 2009 | 2 (91) | 1 (7) | 6 (35) | 12 (97) | 15 (44) | - |
| 2010 | 4 (184) | 2 (34) | 23 (23) | 25 (174) | 38 (153) | 5 (16) |
| 2011 | 3 (258) | 1 (23) | 3 (23) | 19 (170) | 16 (31) | 19 (116) |
| 2012 | 3 (189) | 1 (27) | - | 15 (305) | 13 (64) | 33 (163) |
| 2013 | 5 (264) | 1 (24) | 4 (13) | 42 (665) | 35 (211) | 4 (4) |
| 2014 | 3 (95) | 1 (15) | 17 (34) | 37 (292) | 6 (12) | 32 (64) |
| 2015 | 5 (83) | 1 (5) | 4 (8) | 17 (102) | 8 (8) | 25 (25) |
| 2016 | 3 (71) | 2 (9) | 31 (61) | 9 (117) | 28 (28) | 36 (36) |
| 2017 | 3 (35) | 2 (17) | 25 (25) | 5 (5) | 12 (23) | 62 (123) |
| 2018 | 3 (61) | 6 (12) | 11 (11) | 22 (155) | 26 (79) | 27 (27) |
| 2019 | 2 (76) | 1 (13) | 9 (9) | 15 (73) | 4 (4) | - |
| 2020 | 3 (32) | 1 (1) | - | - | 18 (18) | - |

The majority (88%) of tests were conducted separately from survey lines, although the proportion of tests that were followed immediately by a survey line was greater on site surveys (where line changes are short) and VSP operations (where operations are often static so could be ready to start on completion of a test) compared to other survey types (Table 24). Correspondingly, tests on site surveys and VSPs more often reached full power, ready to commence a survey line. The average duration of a test when conducted separately from a survey line did not exceed 40 minutes except for 4D surveys, where tests were often performed during undershooting. When tests continued into survey lines without a break the duration tended to be longer, but often incorporated a full soft start; again, 4D surveys had the longest tests. However, test durations for 4D surveys were less than in 2005–2010, when the mean duration was 52 minutes when not followed by a survey line and 92 minutes when followed by a survey line (Stone 2015). Where full power was reached during testing the average duration of the soft start in 2011–2020 was between 20 and 30 minutes on all survey types; most soft starts met the required minimum duration from commencement to full power, although those on-site surveys did so less than on other survey types.

**Table 24.** Airgun tests in the UKCS between 2011 and 2020.

| Descriptor | Site | VSP | 2D | 3D | 4D | OBS |
|---|---|---|---|---|---|---|
| % tests followed immediately by a survey line | 24.1 | 31.5 | 7.6 | 7.0 | 4.6 | 6.1 |
| Mean duration per test (minutes) when not followed immediately by a survey line | 20 | 37 | 33 | 35 | 41 | 36 |
| Mean duration per test (minutes) when followed immediately by a survey line | 31 | 34 | 52 | 55 | 67 | 49 |
| % tests that reached full power (excluding mini airguns) | 66.4 | 85.6 | 23.9 | 19.3 | 29.9 | 38.9 |
| Mean duration (minutes) of soft start where full power was reached (excluding mini airguns) | 21 | 23 | 27 | 27 | 23 | 22 |
| % soft starts of required minimum duration where full power was reached (excluding mini airguns) | 84.0 | 95.2 | 94.7 | 93.9 | 90.5 | 97.5 |
| Sample size of tests | 1,168 | 146 | 184 | 1,884 | 478 | 558 |

### 3.7.2 High resolution surveys

Typically, there were low numbers of tests of high-resolution sources per survey (Table 25). The mean duration of tests was 46 minutes, and the majority (92%) were run separately from survey lines. High resolution sources reached (or started at) full power on 86% of tests. A soft start of the required minimum duration was performed on 67% of tests where the source began from silence and reached full power and the consent required a soft start of at least 20 minutes, but on 28% of these tests there was no soft start.

**Table 25.** Mean number of high-resolution source tests per survey (and total per year) within the UKCS since August 2017.

| Year | Mean tests per survey (and total) |
|---|---|
| 2017 | 2(15) |
| 2018 | 3(105) |
| 2019 | 3(149) |
| 2020 | 5(69) |

## 3.8 Line change

### 3.8.1 Surveys using airguns

Site surveys, VSPs (for line changes or repositioning geophones) and OBS surveys continued firing during short line changes more often than other survey types (Table 26). 2D, 3D and 4D surveys mostly had longer line changes and stopped firing during the turn.

**Table 26.** Number (and percentage) of line changes on surveys in the UKCS where airguns continued to fire throughout the turn (data for 2009 are from July onwards).

| Year | Site | VSP | 2D | 3D | 4D | OBS |
|---|---|---|---|---|---|---|
| 2009 | 985 (69.4) | 0 (0.0) | 0 (0.0) | 4 (1.2) | 0 (0.0) | 74 (90.2) |
| 2010 | 2,444(77.0) | 1 (5.0) | 0 (0.0) | 0 (0.0) | 1 (0.2) | 1,611(84.2) |
| 2011 | 3,506(76.5) | 22(51.2) | 240(70.0) | 3 (0.3) | 0 (0.0) | 1,210(32.8) |
| 2012 | 2,846(69.0) | 4(11.4) | - | 3 (0.2) | 0 (0.0) | 886 (44.5) |
| 2013 | 3,036(65.5) | 33(39.8) | 0 (0.0) | 0 (0.0) | 1 (0.1) | 2 (1.1) |
| 2014 | 756 (44.1) | 18(46.2) | 1 (1.7) | 45 (8.7) | 0 (0.0) | 2 (0.2) |
| 2015 | 559 (42.9) | 0 (0.0) | 0 (0.0) | 4 (1.2) | 0 (0.0) | 0 (0.0) |
| 2016 | 590 (38.0) | 17(81.0) | 3 (1.6) | 0 (0.0) | 0 (0.0) | 106 (14.6) |
| 2017 | 266 (36.2) | 42(76.4) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| 2018 | 740 (58.7) | 18(78.3) | 0 (0.0) | 1 (0.2) | 1 (0.4) | 0 (0.0) |
| 2019 | 1,718(73.2) | 110(57.6) | 1(50.0) | 11 (2.4) | 0 (0.0) | - |
| 2020 | 406 (68.1) | - | - | - | 0 (0.0) | - |

Between 2011 and August 2017, 95% of surveys with large arrays (≥ 500 cu.in.) where firing continued during short line changes were OBS surveys. In some years airguns were often active for more than the permitted 20 minutes during line changes (without an exemption being sought), with a substantial proportion exceeding the permitted duration by more than 10 minutes between 2014 and 2016 (Table 27).

**Table 27.** Duration of line changes in the UKCS where airguns of volume ≥ 500 cu.in. continued firing throughout; number (and percentage) within or exceeding the permitted duration (prior to August 2017 and excluding surveys where there was an exemption allowing firing to continue for longer; data for 2009 are from July onwards).

| Year | Within permitted duration (≤ 20 mins) | 21–30 mins | > 30 mins |
|---|---|---|---|
| 2009 | 68 (87.2) | 10 (12.8) | 0 (0.0) |
| 2010 | 105 (59.7) | 54 (30.7) | 17 (9.7) |
| 2011 | 313 (31.4) | 656 (65.9) | 27 (2.7) |
| 2012 | 428 (86.6) | 55 (11.1) | 11 (2.2) |
| 2013 | 29 (80.6) | 1 (2.8) | 6 (16.7) |
| 2014 | 2 (50.0) | 0 (0.0) | 2 (50.0) |
| 2015 | 1 (25.0) | 0 (0.0) | 3 (75.0) |
| 2016 | 20 (15.9) | 5 (4.0) | 101 (80.1) |
| 2017 | 28 (90.3) | 1 (3.2) | 2 (6.5) |

Exemptions were agreed for several OBS surveys and one VSP, with JNCC allowing them to continue firing during slightly longer line changes (25 or 30 minutes for OBS, 40 minutes for VSP) than would have been allowed under the 2010 version of the guidelines. Where exemptions were allowed, compliance with the agreed duration for continued firing was generally better (Table 28) than when there was no exemption (Table 26) and few exceeded the permitted duration by more than 10 minutes. However, between 2015 and August 2017, although non-compliance was sometimes high, there were no surveys where exemptions were sought to resolve any difficulties they were experiencing.

**Table 28.** Number (and percentage) of line changes where firing was within or exceeded the permitted duration where an exemption allowed firing to continue for longer than 20 minutes throughout the line change (surveys in the UKCS with airgun volume ≥ 500 cu.in., prior to August 2017; data for 2009 are from July onwards).

| Year | Within permitted duration | Exceeded permitted duration by ≤ 10 mins | Exceeded permitted duration by > 10 mins |
|---|---|---|---|
| 2009 | - | - | - |
| 2010 | 930 (77.2) | 256 (21.3) | 18 (1.5) |
| 2011 | 207 (95.0) | 11 (5.0) | 0 (0.0) |
| 2012 | 377 (95.4) | 14 (3.5) | 4 (1.0) |
| 2013 | - | - | - |
| 2014 | 18 (94.7) | 1 (5.3) | 0 (0.0) |
| 2015 | - | - | - |
| 2016 | - | - | - |
| 2017 | - | - | - |

Where firing continued during line changes on surveys with smaller airgun volumes (≤ 180 cu.in.) prior to August 2017, most line changes were completed within the 40 minutes allowed by the guidelines (Table 29).

**Table 29.** Duration of line changes in the UKCS where airguns of volume ≤ 180 cu.in. continued firing throughout; number (and percentage) within or exceeding the permitted duration (prior to August 2017; data for 2009 are from July onwards).

| Year | Within permitted duration (≤ 40 mins) | 41–50 mins | > 50 mins |
|---|---|---|---|
| 2009 | 873 (88.6) | 66 (6.7) | 46 (4.7) |
| 2010 | 2,265 (92.9) | 141 (5.8) | 33 (1.4) |
| 2011 | 3,463 (95.1) | 121 (3.3) | 58 (1.5) |
| 2012 | 2,749 (96.6) | 78 (2.7) | 19 (0.7) |
| 2013 | 2,890 (95.2) | 114 (3.8) | 32 (1.1) |
| 2014 | 775 (97.0) | 19 (2.4) | 5 (0.6) |
| 2015 | 544 (97.3) | 14 (2.5) | 1 (0.2) |
| 2016 | 586 (99.3) | 2 (0.3) | 2 (0.3) |
| 2017 | 205 (92.8) | 15 (6.8) | 1 (0.5) |

Between 2011 and August 2017 there were a small number of surveys with airgun volumes between 180 cu.in. and 500 cu.in. Three were VSPs with airgun volumes of 250 cu.in., of which one kept firing between lines for periods of over an hour at a time. Two were site surveys with airgun volumes of 420 cu.in., where firing continued during line changes of up to 40 minutes. There were also two 2D surveys with airgun volumes of 470 cu.in. where the regulator required the airguns to continue firing during all line changes of any duration.

After August 2017 site surveys and VSPs were the survey types that most often continued firing during line changes / repositioning geophones (Table 26). The majority of line changes where the airguns remained firing were completed within the permitted 40 minutes (Table 30), although VSPs often lacked the detail needed in the data to assess compliance when repositioning geophones (see section 3.9).

**Table 30.** Duration of line changes in the UKCS where airguns (of any volume) continued firing throughout; number (and percentage) within or exceeding the permitted duration (August 2017 onwards).

| Year | Within permitted duration (≤ 40 mins) | 41–50 mins | > 50 mins |
|---|---|---|---|
| 2017 | 48 (85.7) | 3 (5.4) | 5 (8.9) |
| 2018 | 747 (98.3) | 9 (1.2) | 4 (0.5) |
| 2019 | 1,817 (98.8) | 15 (0.8) | 8 (0.4) |
| 2020 | 405 (99.8) | 0 (0.0) | 1 (0.2) |

Where airguns continued firing without permission during longer line changes between 2011 and 2020, there were a few occasions where this was particularly prolonged; 82 exceeded one hour, of which 10 exceeded two hours. Amongst the reasons given for airguns firing for longer periods during line changes (without permission), the most common were:

- currents or tides affecting the speed of the vessel
- poor weather affecting the speed of the vessel
- technical problems resulting in a longer line change

- miscalculation of turn times
- navigation problems
- communication problems
- shift changeover during the line change
- misunderstanding of guidelines by the crew
- needing to avoid other vessels or fishing gear.

There were some occasions where firing continued after the end of line for a while before stopping, mostly on-site surveys and VSPs. Between 2011 and 2020, the airguns continued for more than 10 minutes after the end of line before stopping on 4% of occasions on site surveys and 3% of occasions on VSPs. Sometimes it was recorded that firing initially continued as the line change was anticipated to be completed within 40-minutes but ceased when it became apparent that it would take longer.

There were also occasions on site surveys using airguns and high-resolution sources (sub-bottom profilers) simultaneously where the airguns ceased firing during a line change, but the sub-bottom profilers continued to be active. Between 2014 and 2020 this was recorded on 368 occasions, representing 4% of line changes where airguns were used. On most occasions (78%) the line change took more than 40 minutes; although the airguns were stopped the sub-bottom profilers were kept running, sometimes for prolonged periods. On 25% of occasions when sub-bottom profilers continued after airguns stopped the line change lasted more than an hour, with the maximum duration being 13 hours and 46 minutes, when a hull-mounted chirp was left active after a test until the next line the following day.

There were 92 surveys between 2011 and 2020 that utilised a single mini airgun (including those with a volume of 12 cu.in. as well as up to 10 cu.in. as defined in the guidelines). On 75% of those surveys where operations data were correctly recorded, the mini airgun was routinely kept firing during short line changes expected to take less than 40 minutes. The average line duration for a single mini airgun was 34 minutes, with the average duration of continued firing during line changes being 23 minutes.

On VSP operations between 2011 and 2020 it was common to fire ‘mitigation shots’ at intervals while repositioning geophones (see section 3.9), sometimes for prolonged periods, although this is not a procedure included in the guidelines. There were also a few occasions on 10 surveys (other than VSP) when a ‘mitigation gun’ was fired for a period, often prolonged, during line changes or other breaks in firing. On most surveys where a ‘mitigation gun’ was used there was no permission. Permission was granted for a ‘mitigation gun’ to be used during night-time line changes on two surveys when PAM could not be used: on a 3D survey in 2015 due to failure of the PAM equipment and on a 2D survey in 2016 due to weather conditions preventing PAM array deployment (although the same survey had previously used a ‘mitigation gun’ for prolonged periods during intermittent testing of the airguns without seeking permission). On two surveys where a ‘mitigation gun’ was used for prolonged periods between tests the MMOs / PAM operators advised the crew against this, but the crew decided to go ahead against their advice. Where a ‘mitigation gun’ was used without permission various reasons were given for its use:

- to avoid the need for a pre-shooting search at night on an occasion when the PAM array could not be deployed due to weather
- during darkness when PAM equipment was faulty until it could be replaced
- during darkness when there was no PAM on board
- after the end of or between tests

- after aborting a soft start before doing another soft start
- due to a decision by the seismic crew at the beginning of a survey (before being stopped on advice of the MMO)
- due to uncertainties regarding correct procedures
- the operator mistakenly believing they had been given dispensation allowing use of a 'mitigation gun' during gaps of up to 120 minutes during seismic while drilling operations.

### 3.8.2 High resolution surveys

Prior to the 2017 guidelines revision there was uncertainty regarding best practice for the use of high-resolution sources during line changes and crews often applied their own interpretations. In one case in 2014 the source was kept active during line changes at the client's request "to avoid delays due to marine animal sightings", following several marine mammal sightings at the beginning of the survey.

Since August 2017, when the guidelines recommended the same procedures are used during line changes with high resolution sources as are used for airguns, surveys using high resolution sources often had relatively short line changes and therefore the source often remained active during the line change (Table 31). On most occasions, the line change was completed within the permitted 40 minutes (Table 32). Where the source was active during prolonged line changes, the reasons were often the same as for airguns, such as weather or currents slowing the vessel during the turn. However, a couple of reports noted that where MMOs had a dual role on board their focus was elsewhere outside the required searches, so may not have been available to monitor compliance and advise the crew. On 6% of occasions the sources continued for more than 10 minutes after the end of a survey line before stopping, often because it was initially anticipated that the line change would be completed within 40 minutes.

**Table 31.** Number (and percentage) of line changes where high-resolution sources (without airguns) remained active throughout the turn on surveys in the UKCS (August 2017 onwards).

| Year | Line changes with active source |
|---|---|
| 2017 | 66(78.6) |
| 2018 | 1,466(79.0) |
| 2019 | 1,772(67.7) |
| 2020 | 550(82.1) |

**Table 32.** Duration of line changes in the UKCS where high resolution sources (without airguns) remained active throughout; number (and percentage) within or exceeding the permitted duration (August 2017 onwards).

| Year | Within permitted duration (≤ 40 mins) | 41–50 mins | > 50 mins |
|---|---|---|---|
| 2017 | 61 (92.4) | 5 (7.6) | 0 (0.0) |
| 2018 | 1,455 (99.2) | 6 (0.4) | 5 (0.3) |
| 2019 | 1,759 (99.3) | 6 (0.3) | 7 (0.4) |
| 2020 | 548 (99.6) | 1 (0.2) | 1 (0.2) |

## 3.9 VSP operations

There was a lack of detail in the data regarding the timing of operations at different levels and repositioning of equipment between levels. Of 115 VSPs between 2011 and 2020, 65% recorded only one or two periods of activity, often prolonged and presumably covering multiple positions. However, in some cases MMO reports provided information on the general procedures used during these periods of activity, even though precise details were lacking.

There were 97 VSP surveys between 2011 and August 2017; on 57 of these 'mitigation shots' were fired at intervals of less than 10 minutes (typically nine minutes) when repositioning the geophone between levels to avoid the need for another soft start (i.e. adopting the allowance for resuming without a soft start following an unplanned break in firing of less than 10 minutes, although repositioning cannot be considered an unplanned break). Reports from only two surveys recorded discussing this with JNCC; on one it was agreed that 'mitigation shots' at operational level at less than 10 minute intervals could be fired for a period of up to 60-minutes (which could be extended by a further 30 minutes if necessary), while on the other a shot interval of five minutes and a maximum duration for continued firing of 40-minutes was recommended (although there was one occasion when the 'mitigation shots' continued for 1 hour 57 minutes after a test on this survey, due to "Confusion over mitigation shots"). On many of the surveys where 'mitigation shots' were used there was little detailed information on how long such firing lasted, but some reports noted that a 'mitigation gun' was used on occasion for prolonged periods, including one instance of over four hours.

Between August 2017 and the end of 2020 there were 18 VSP surveys, of which eight recorded using 'mitigation shots' when repositioning. Whereas prior to August 2017 such shots were commonly fired at nine-minute intervals, reports since 2017 did not usually include details of the interval between shots, except for one in 2019 where it was stated that a nine-minute shot interval was used. Often repositioning the geophones at different levels was not recorded in sufficient detail to establish how long the use of 'mitigation shots' continued whilst repositioning, but where it was recorded in detail, firing intermittent shots continued for more than 40 minutes on 10% of occasions (compared to 1% of occasions where firing continued for more than 40 minutes during line turns on other survey types since August 2017). Some reports noted the difficulty of estimating the time taken for repositioning and the potential complications from having the toolstring stationary in the wellbore while performing another soft start, so for this reason intermittent shots were sometimes continued for longer rather than stopping. There were also some VSPs where they were not ready to commence operations after the soft start was completed, so 'mitigation shots' were used after reaching full power. On one such survey, a cycle of alternating soft starts and 40 minutes of 'mitigation shots' was employed until ready for the start of operations on two occasions, leading to a total of three hours excess firing.

There was one VSP operation in 2013 where JNCC allowed longer soft starts to commence with grey seals in the mitigation zone, as the seals had taken up residence on the platform. The report states that a 'mitigation gun' was used thereafter to prevent animals returning to the mitigation zone, although there is no record that this was agreed with JNCC. The report noted that the seals returned after the source stopped.

On 43 of the 115 VSP operations between 2011 and 2020 there was a single dual role MMO / PAM operator who did either visual or acoustic monitoring depending on conditions. On three of these surveys there was a non-dedicated MMO to assist with visual monitoring but on the others the single operative had to choose between visual or acoustic monitoring in daylight. PAM was sometimes prioritised over visual monitoring, with the result that on 21% of occasions there was no visual pre-shooting search when operations commenced during daylight; on these occasions PAM was used instead, but on only two occasions was this noted as being due to observation conditions (once due to poor visibility and once due to increased sea states).

## 3.10 Passive Acoustic Monitoring

### 3.10.1 Use of PAM on surveys using airguns

The proportion of surveys with airguns using PAM increased steadily from 2011; by 2018 almost all surveys were using PAM (Figure 4). All types of survey used PAM, but there was particularly an increase in the number of site surveys and VSPs using PAM (Figure 5).

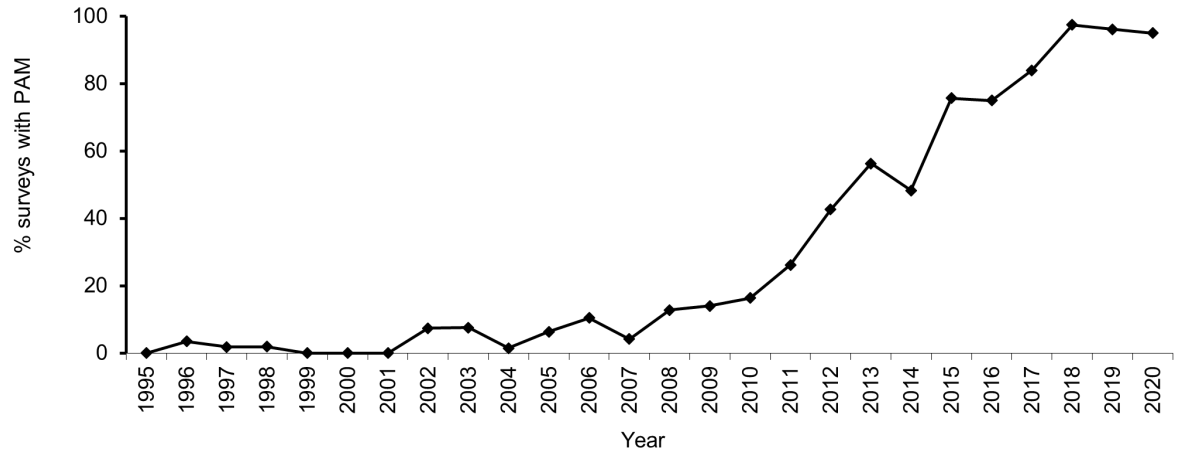


**Figure 4.** Percentage of surveys with airguns using PAM.

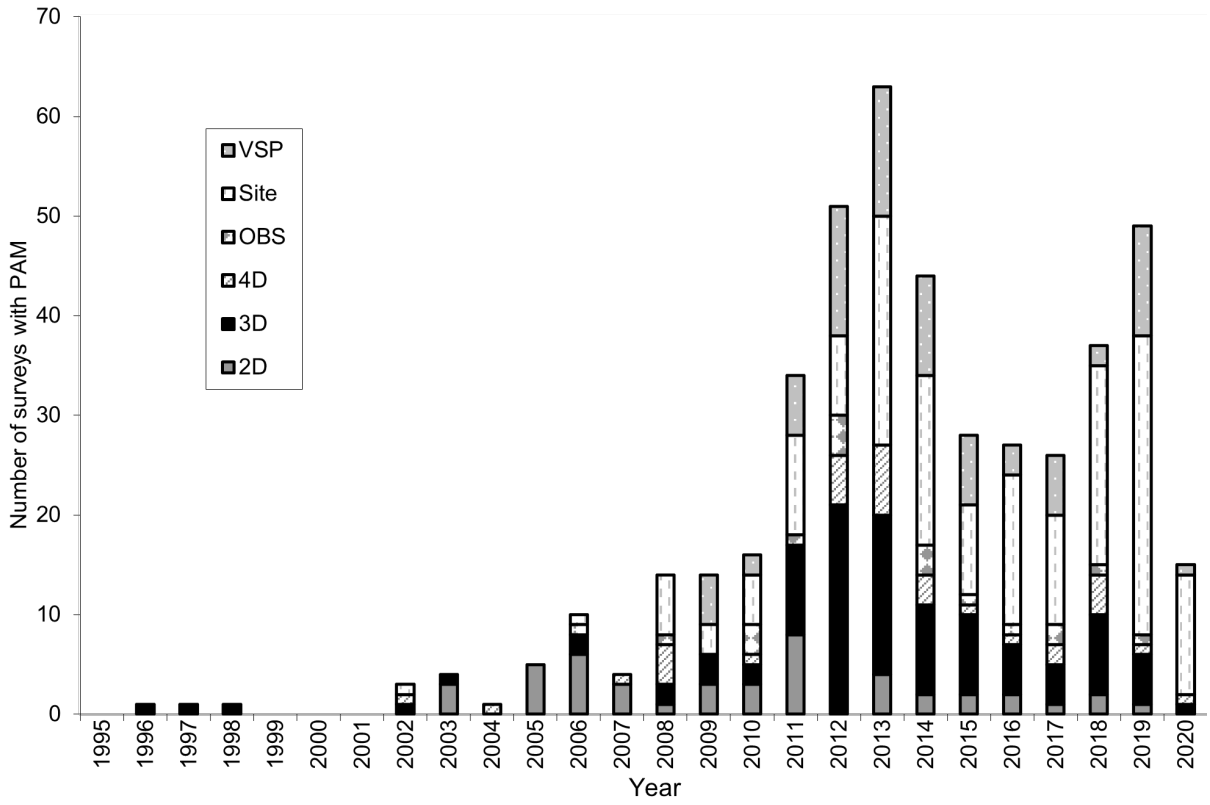


**Figure 5.** Use of PAM on different types of survey using airguns.

In 2011–2020 PAM was used mostly in the North Sea and around Shetland, reflecting the location of surveys throughout the period (Table 33).

**Table 33.** Location of airgun surveys using PAM, 2011–2020 (some surveys were in more than one area).

| Area | Number of surveys using PAM | Total number of surveys |
|---|---|---|
| West of Shetland | 69 | 72 |
| North of Shetland | 30 | 52 |
| Northern North Sea | 97 | 159 |
| Outer Moray Firth | 25 | 36 |
| Central North Sea | 142 | 257 |
| Southern North Sea | 40 | 75 |
| Rockall | 2 | 2 |
| Irish Sea | 4 | 11 |
| St George's Channel | 1 | 1 |
| South-west Approaches | 1 | 1 |
| English Channel | 1 | 2 |

From 2012 onwards there was an increase in the proportion of occasions where PAM was used prior to commencing firing at night; by 2020 there were no occasions when airguns commenced firing at night without PAM beforehand (Figure 6), although the duration of the search was occasionally inadequate (section 3.3.1).

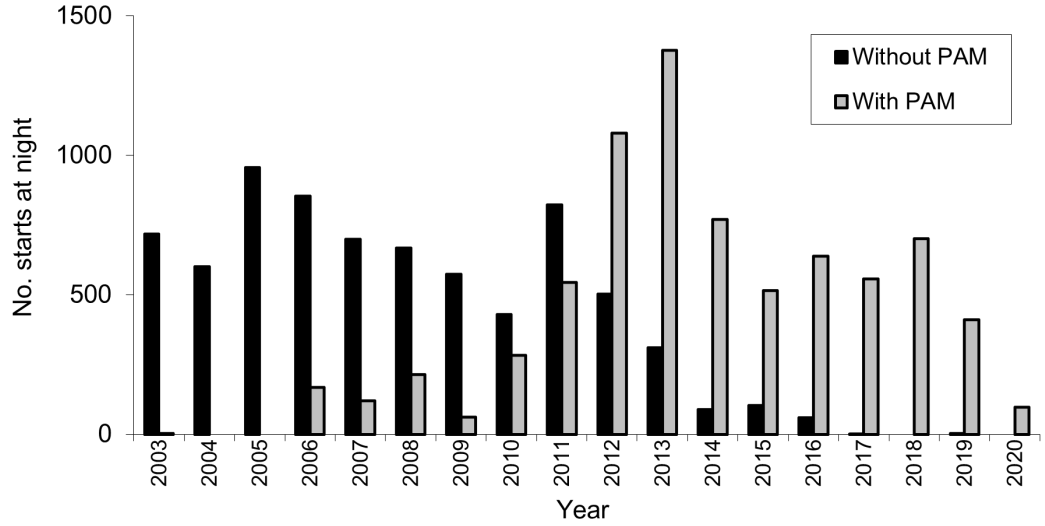


**Figure 6.** Number of times airguns commenced firing at night within the UKCS with and without PAM.

Over the period from 2011 to 2020 there was increasing use of PAM in suboptimal or very poor weather conditions, although in some years there were still more occasions when firing started in these conditions without PAM than with PAM (Figure 7 and Figure 8). However, on some occasions when PAM was used in suboptimal or very poor weather conditions in daytime it was used as a substitute for the visual search rather than in addition to it. There were 338 occasions when airguns commenced firing in daylight and there was an acoustic search instead of a visual search, of which at least 191 were due to weather conditions. Sometimes the number of mitigation personnel limited the ability to use visual monitoring and PAM concurrently, but on 69 of the 338 occasions visual monitoring could have continued alongside the acoustic monitoring as there were four mitigation personnel on board (two MMOs and two PAM operators); a further 166 occasions occurred when there were two MMOs and one PAM operator on board. Even in very poor weather conditions ('rough' sea state, 'large' swell or 'poor' visibility) marine mammals were still sometimes detected visually, with 122 visual detections in such conditions on surveys with airguns between 2011 and 2020, compared to 25 acoustic detections and seven detections made by both methods. Sample sizes were too low to test detection rates using different monitoring methods in very poor conditions whilst allowing for other variables that may have influenced detections (e.g. location or season), but in suboptimal sea conditions visual detection rates were usually higher than acoustic detection rates (see section 3.10.3).

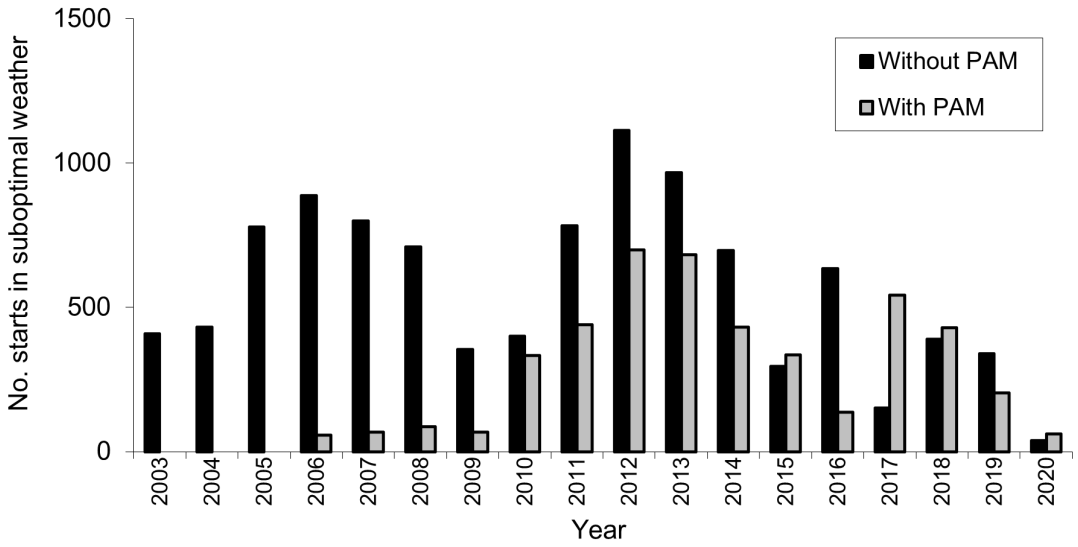


**Figure 7.** Number of times airguns commenced firing in suboptimal weather ('choppy' or 'rough' sea state or 'medium' or 'large' swell or 'moderate' or 'poor' visibility) within the UKCS with and without PAM.

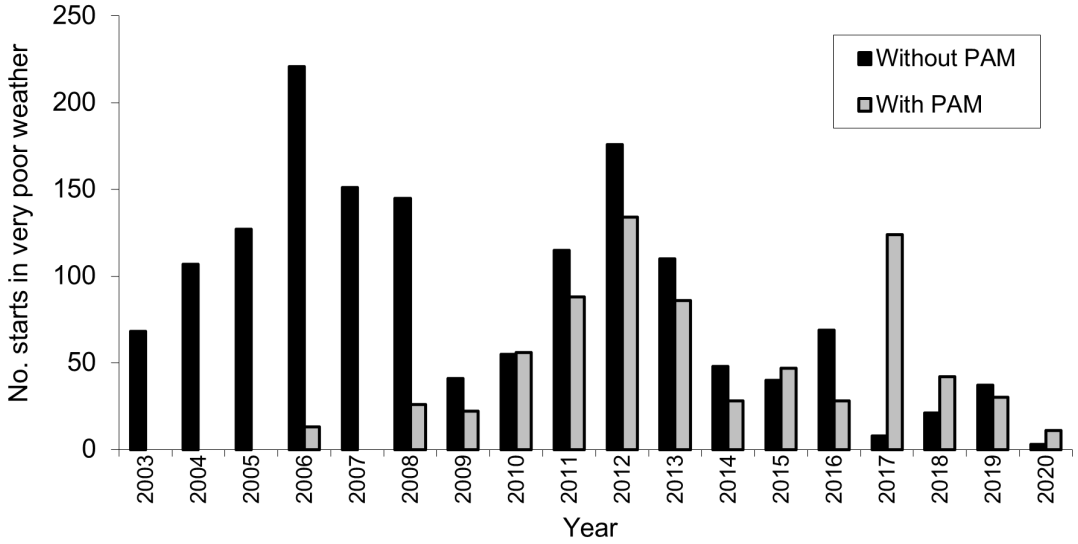


**Figure 8.** Number of times airguns commenced firing in very poor weather ('rough' sea state or 'large' swell or 'poor' visibility) within the UKCS with and without PAM.

Although there was increasing use of PAM throughout the period, visual monitoring was still the predominant method overall. Of surveys using both visual monitoring and PAM, 68% recorded more hours spent visual monitoring than acoustic monitoring. PAM was used primarily at night; only 20% of surveys using PAM between 2011 and 2020 used it routinely (on at least 50% occasions) prior to operations commencing in daylight to complement visual searches, while 46% used it only at night. Routine use of PAM during the day appeared to be related to the number of PAM operators (see section 3.11), with those surveys routinely using it in daylight more often having two or more PAM operators compared to those where PAM was not routinely used in daylight. Where the consent required that PAM was used during the day to complement the visual search, the airguns often commenced firing without PAM beforehand (Figure 9; the high number of occasions where firing started in daylight without PAM in 2016 came from one OBS survey). On 97% of occasions where firing commenced in daylight without PAM (where the consent required its use) there was only one PAM operator.

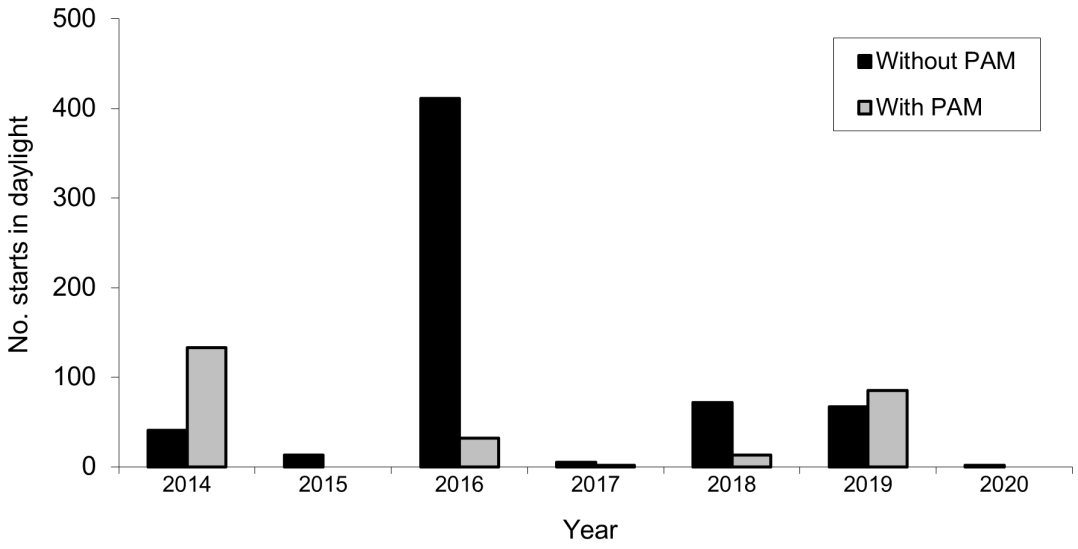


**Figure 9.** Number of times airguns commenced firing in daylight within the UKCS with and without PAM (where consents required PAM to be used to complement the visual search in daylight).

Between 2011 and 2020 most delays were for animals detected visually (Figure 10). On surveys where both PAM and visual monitoring were used, the rate at which delays were required was significantly greater for visual detections (1.14 delays required per 1,000 hours visual observations and 0.61 delays required per 1,000 hours acoustic monitoring, $\chi^2$ = 9.148, d.f. = 1, $p < 0.01$). However, there were 29 delays for marine mammals that were only detected acoustically (= 19% of delays). Of these, 21 occurred at night when there would have been no means of detecting marine mammals had PAM not been used. There were also eight delays for animals that were detected both visually and acoustically – of these, three were first detected acoustically and potentially may have escaped detection otherwise. Correct procedures were implemented for 88% of delays following visual detections and 93% of delays following acoustic detections.

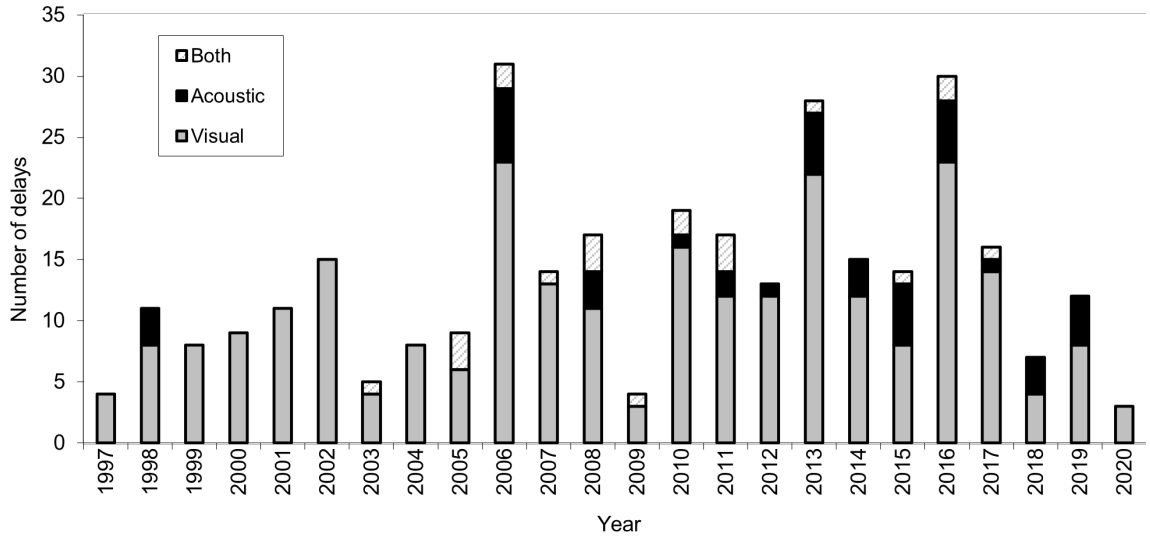


**Figure 10.** Delays on surveys with airguns in the UKCS due to marine mammals detected by visual or acoustic means.

Range estimation was sometimes difficult with PAM and for 12 of the 29 acoustic detections where delays were implemented between 2011 and 2020 there was no estimate of the range. There were an additional four acoustic detections without range estimates where

delays were not implemented, and the timings were such that delays would have been required if the animals were in the mitigation zone. It is possible the animals were outside the mitigation zone, but no justification was given for not delaying in these cases.

The most common or notable issues reported with the use of PAM in 2011–2020 included:

- being unable to deploy the PAM array due to weather
- needing to recover the PAM array during turns in one direction
- needing to recover the PAM array when airguns were being recovered or deployed
- difficulties with deployment due to the particular set up of seismic gear / winches on the vessel
- being unable to retrieve or adjust the PAM cable due to deployment issues
- entanglement with the seismic streamers / airguns (at least 22 cases)
- severed (at least 11 cases) or damaged PAM cables
- PAM being deployed for pre-shooting searches only, due to the risk of entanglement
- hardware failure (hydrophone element, depth sensor, hydrophone cable, deck cable, sound card, connections, PC)
- delay in providing replacement equipment in the event of a hardware failure
- failure of both original and replacement equipment
- software issues (low signal detection, configuration settings, localisation plug-ins not working, crashes, error messages, drivers)
- supplied equipment being inadequate (configuration file inappropriate, sound card with insufficient sampling rate for high frequency vocalisations, wires incorrectly labelled and inserted into wrong ports, previous repairs being a weak point leading to failures, equipment not robust enough for sea conditions, PAM cable too short)
- noise interference due to vessel noise (e.g. propeller wash, engines, thrusters) or electrical interference
- pings from transducers close to frequencies of delphinids / beaked whales / porpoises, potentially masking signals
- difficulty with ranging / localisation of detections
- positioning the hydrophones so far ahead of the airguns that the mitigation zone was not adequately covered
- positioning the hydrophones so far ahead of the airguns that when delaying due to detections, at the stage when the animals were no longer detected by PAM and operations commenced, they could be within the mitigation zone
- lack of confidence in the ability of PAM to detect marine mammals as the airguns were not detected
- failure to detect animals visually observed to be in close proximity to the PAM hydrophones.

For a small number of surveys, towing the PAM arrays from the airgun arrays was seen as an improvement as it reduced the risk of entanglement and minimised the need for the PAM operator to be involved in deployment, leading to reduced safety risks.

### 3.10.2 Use of PAM on high resolution surveys

The proportion of high-resolution surveys (without airguns) using PAM steadily increased since these surveys were included in the JNCC guidelines in 2017 (Figure 11). By 2019 83% of high-resolution surveys used PAM. However, visual monitoring remained the predominant method, with 70% of surveys where PAM was used recording more hours spent on visual observations than acoustic monitoring.

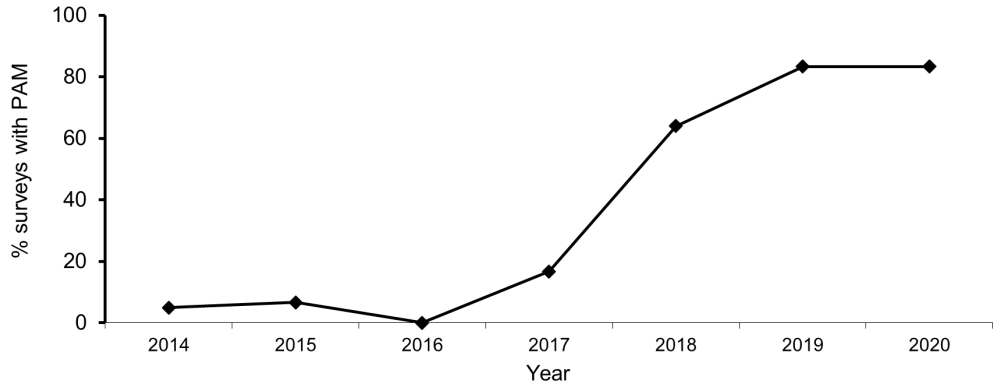


**Figure 11.** Percentage of surveys with high resolution sources (without airguns) using PAM.

In 2014–2020 PAM was used for high resolution surveys mostly in the central and southern North Sea, reflecting the location of these surveys throughout the period (Table 34).

**Table 34.** Location of high-resolution surveys (without airguns) using PAM, 2014–2020 (some surveys were in more than one area).

| Area | Number of surveys using PAM | Total number of surveys |
|---|---|---|
| West of Shetland | 3 | 6 |
| North of Shetland | 3 | 4 |
| Northern North Sea | 6 | 20 |
| Outer Moray Firth | 1 | 5 |
| Central North Sea | 19 | 41 |
| Southern North Sea | 17 | 45 |
| Irish Sea | 0 | 2 |

Since their inclusion in the JNCC guidelines in 2017, there has been an increase in the number of occasions where PAM was used prior to starting high resolution sources at night (Figure 12). In 2020 there were no occasions when operations commenced at night without monitoring with PAM beforehand.

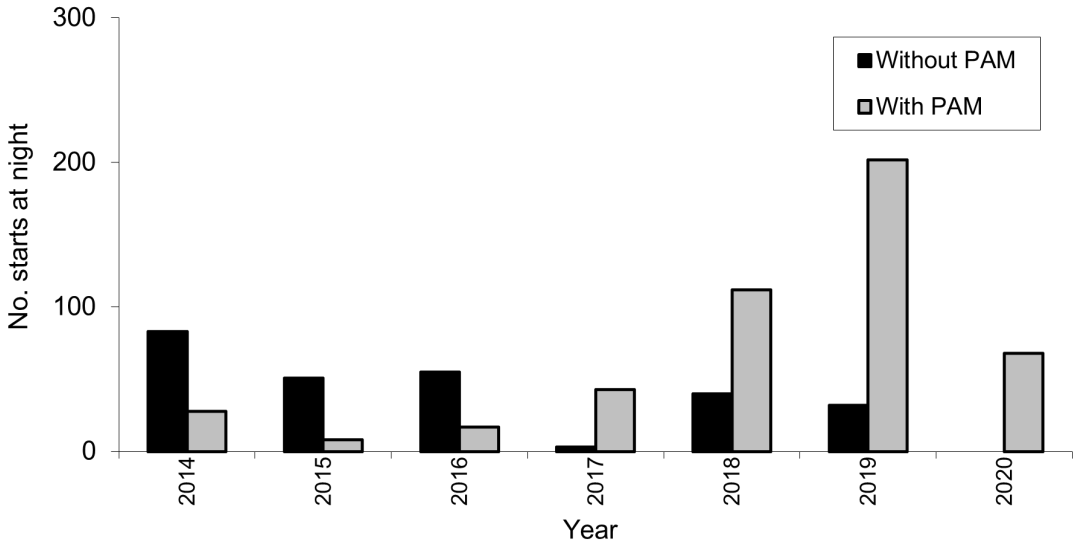


**Figure 12.** Number of times high resolution sources (without airguns) were started at night within the UKCS with and without PAM.

PAM was not so widely used for high resolution sources in suboptimal or very poor weather conditions although the use of PAM in such conditions had increased by 2020 (Figure 13 and Figure 14). When PAM was used in suboptimal weather, there were some occasions when it was used as a substitute for the visual search rather than complementary to it. On 30 occasions high resolution sources commenced activity in daylight with only an acoustic search beforehand, of which at least 17 were due to weather conditions. On nine of the 30 occasions there were two MMOs and one PAM operator on board, while on one occasion there were three MMOs and one PAM operator on board. There were only four detections in very poor conditions ('rough' sea state, 'large' swell, or 'poor' visibility) on high resolution surveys, but these were all visual.

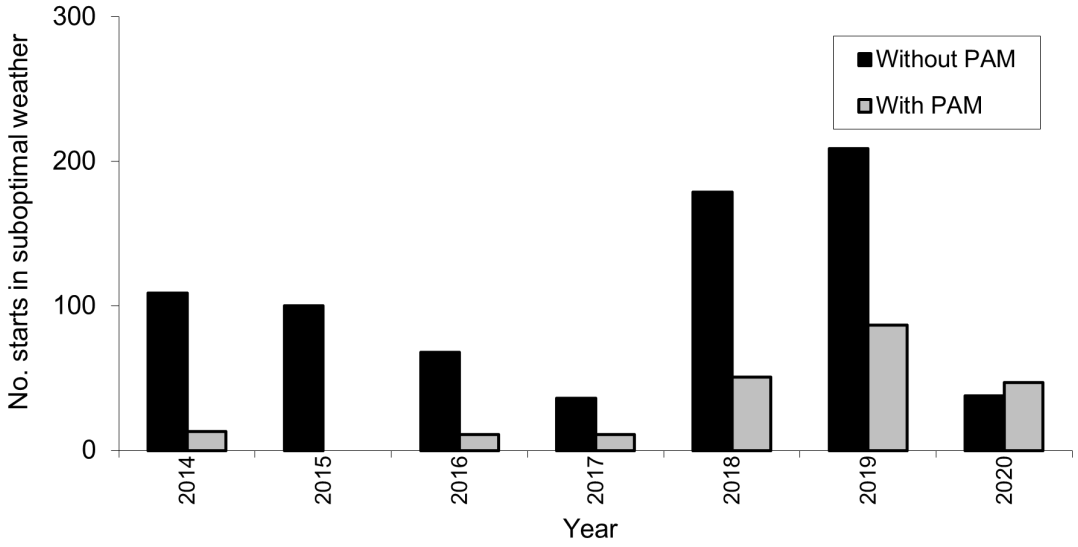


**Figure 13.** Number of times high resolution sources (without airguns) were started in suboptimal weather ('choppy' or 'rough' sea state or 'medium' or 'large' swell or 'moderate' or 'poor' visibility) within the UKCS with and without PAM.

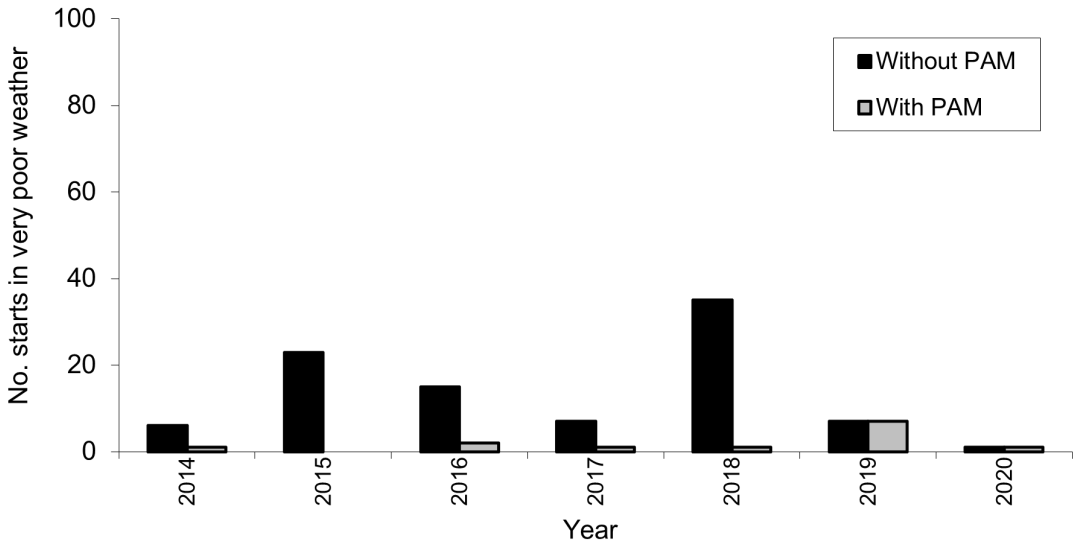


**Figure 14.** Number of times high resolution sources (without airguns) were started in very poor weather ('rough' sea state or 'large' swell or 'poor' visibility) within the UKCS with and without PAM.

Only one high resolution survey using PAM since August 2017 routinely used it during the daytime; the majority (85%) used it only at night. There were not many high resolution surveys where the consent required PAM to be used in daylight alongside visual observations, but when it was required operations often commenced in daylight without PAM (Figure 15); on 52% of occasions where operations commenced in daylight without PAM there was no PAM on board while on 43% of occasions there was PAM but only one PAM operator.

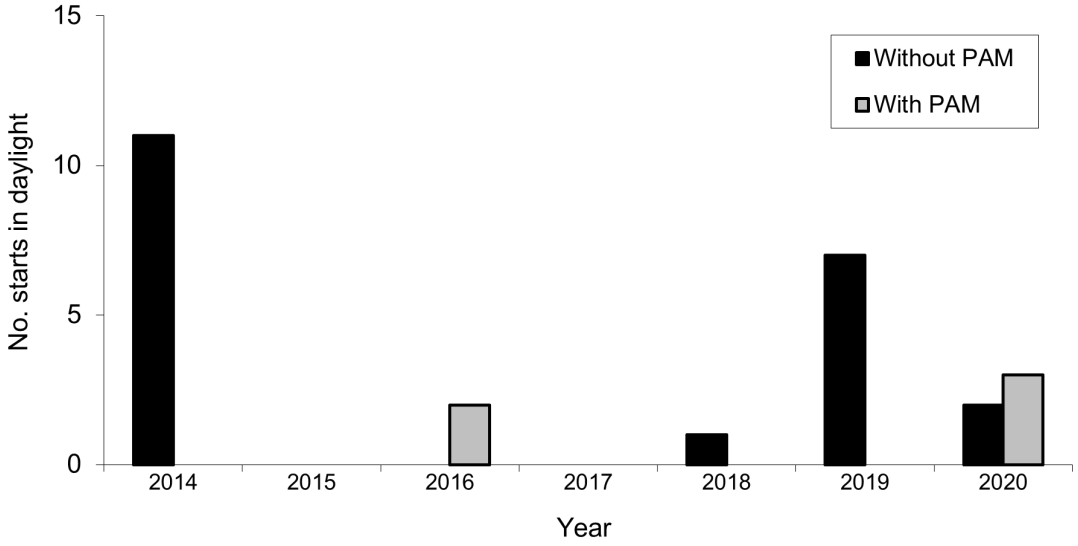


**Figure 15.** Number of times high resolution sources (without airguns) commenced firing in daylight within the UKCS with and without PAM (where consents required PAM to be used to complement the visual search in daylight).

Of the 31 delays in the use of high-resolution sources between 2014 and 2020 due to the presence of marine mammals, only one was due to animals detected acoustically (Figure 16). However, this happened at night when there would have been no means of detecting marine mammals had PAM not been used. Correct procedures were implemented for 71% of delays following visual detections and for the single delay following an acoustic detection (for which there was no estimate of the range).

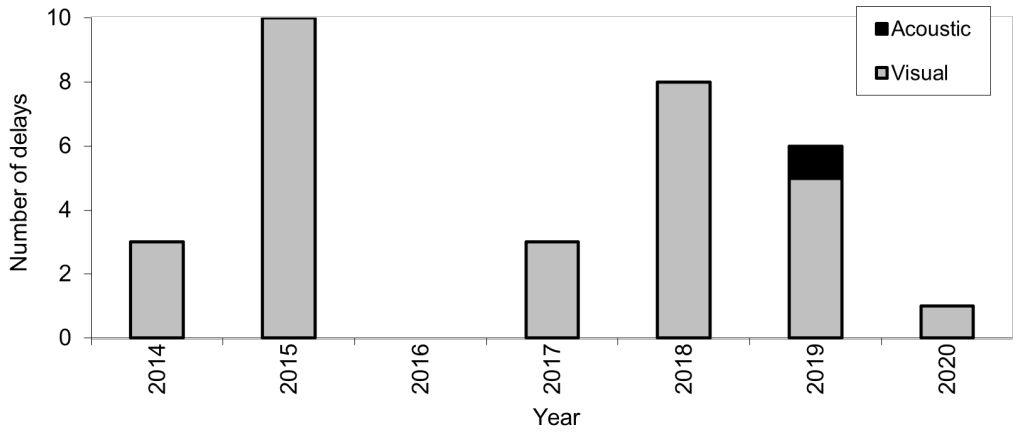


**Figure 16.** Delays on high resolution surveys (without airguns) in the UKCS due to marine mammals detected by visual or acoustic means.

### 3.10.3 Detection rates using PAM compared to visual sighting rates

Most detections of marine mammals during geophysical surveys between 2011 and 2020 were visual (Table 35). The vast majority (98%) of detections were by only one means; only 97 detections were both visual and acoustic. Without visual confirmation identification of animals detected acoustically was mostly (92%) limited to unidentified cetacean, unidentified whale, unidentified dolphin or unidentified delphinid. Sperm whales, long-finned pilot whales and harbour porpoises were identified from their acoustic signatures, with only seven detections being identified as other species without visual confirmation.

**Table 35.** Visual and acoustic detections of marine mammals on geophysical surveys in the UKCS, 2011–2020 (species detected by both methods are included in both columns).

| Species | Number of visual detections | Number of acoustic detections |
|---|---|---|
| Seal sp. | 202 | - |
| Grey seal | 222 | - |
| Harbour seal | 23 | - |
| Cetacean sp. | 457 | 60 |
| Whale sp. | 310 | 5 |
| Large whale sp. | 58 | - |
| Humpback whale | 13 | 1 |
| Blue whale | 1 | - |
| Fin whale | 61 | - |
| Sei whale | 13 | - |
| Humpback / sperm whale | 2 | - |
| Blue / fin / sei whale | 9 | - |
| Fin / sei whale | 50 | - |
| Fin / sei / humpback whale | 4 | - |
| Fin / sei / blue / humpback whale | 149 | - |

| Species | Number of visual detections | Number of acoustic detections |
|---|---|---|
| Fin / blue whale | 19 | - |
| Sperm whale | 91 | 23 |
| Medium whale sp. | 29 | - |
| Minke whale | 523 | 3 |
| Beaked whale sp. | 3 | - |
| Northern bottlenose whale | 3 | - |
| Long-finned pilot whale | 246 | 40 |
| Killer whale | 114 | 5 |
| Delphinid sp. (dolphin, long-finned pilot, killer, false killer whale) | 19 | 86 |
| Dolphin sp. | 608 | 439 |
| Dolphin sp. (not porpoise) | 7 | 1 |
| Risso's dolphin | 15 | 1 |
| Bottlenose dolphin | 35 | 3 |
| White-beaked dolphin | 384 | 8 |
| Atlantic white-sided dolphin | 94 | 18 |
| *Lagenorhynchus* sp. | 14 | 4 |
| Common dolphin | 114 | 6 |
| Striped dolphin | 1 | - |
| Common / striped / white-beaked / Atlantic white-sided dolphin | 4 | - |
| Common / Atlantic white-sided dolphin | 6 | 1 |
| Harbour porpoise | 226 | 7 |
| **Total** | **4,073*** | **705*** |

* Mixed species detections are only counted once in the totals.

Weather conditions influenced the ability of observers to detect marine mammals visually (Table 36). Detection rates were significantly lower in conditions of 'rough' sea states or 'large' swell and declined significantly with decreasing visibility. However, acoustic detection rates were not significantly influenced by sea state or swell (Table 35), although sample sizes for acoustic monitoring were lower than for visual monitoring as PAM operators often did not record weather conditions (section 3.11).

**Table 36.** Cetacean detection rate in relation to weather conditions, tested using the Friedman two-way analysis of variance by ranks (Fr = Friedman statistic; n = number of matched samples for detection rates at the different conditions). Multiple pairwise comparisons of treatments were made using the Wilcoxon signed ranks test (T+ = sum of ranks of matched pairs where detection rate at the first condition exceeded detection rate at the second condition; z = Wilcoxon statistic for large samples; n = number of matched pairs; adjusted p-value = adjusted using the Bonferroni correction for multiple comparisons; d.f. =1). Significant results are in bold.

| **Weather and monitoring method: Sea state (visual monitoring)** | **Median detection rate per hr** ***(+ 1st and 3rd quartiles)*** | **Friedman test** | **p-value** | **Pairwise comparisons** | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **Pair** | **$T^+$** | **z** | **n** | **Adjusted p-value** |
| 'Glassy' (G) | *0.00* 0.00 *0.11* | $F_r$ = 68.516 | **< 0.001** | G-S | 1,017 | -0.154 | 64 | 1.000 |
| 'Slight' (S) | *0.01* 0.04 *0.09* | n = 107 | | G-C | 766 | 2.138 | 47 | 0.097 |
| 'Choppy' (C) | *0.00* 0.01 *0.04* | d.f. = 3 | | G-R | 412 | 4.209 | 29 | **< 0.001** |
| 'Rough' (R) | *0.00* 0.00 *0.00* | | | S-C | 1,828 | 4.304 | 67 | **< 0.001** |
| | | | | S-R | 1,845 | 6.089 | 62 | **< 0.001** |
| | | | | C-R | 696 | 4.270 | 39 | **< 0.001** |

| **Weather and monitoring method: Sea state (PAM)** | **Median detection rate per hr** ***(+ 1st and 3rd quartiles)*** | **Friedman test** | **p-value** | **Pairwise comparisons** | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **Pair** | **$T^+$** | **z** | **n** | **Adjusted p-value** |
| 'Glassy' (G) | *0.00* 0.00 *0.00* | $F_r$ = 1.399 | > 0.05 | | | | | |
| 'Slight' (S) | *0.01* 0.02 *0.10* | n = 17 | | | | | | |
| 'Choppy' (C) | *0.00* 0.00 *0.00* | d.f. = 3 | | | | | | |
| 'Rough' (R) | *0.00* 0.00 *0.00* | | | | | | | |

| Weather and monitoring method: Swell (visual monitoring) | Median detection rate per hr *(+ 1st and 3rd quartiles)* | Friedman test | p-value | Pairwise comparisons | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Pair | $T^+$ | z | n | Adjusted p-value |
| 'Low' (0–2 m) (O) | *0.01* 0.04 *0.08* | $F_r$ = 40.355 | | O-M | 1,484 | 1.900 | 68 | 0.086 |
| 'Medium' (2–4 m) (M) | *0.00* 0.00 *0.06* | n = 268 | **< 0.001** | O-L | 1,444 | 4.219 | 59 | **< 0.001** |
| 'Large' (> 4 m) (L) | *0.00* 0.00 *0.00* | d.f. = 2 | | M-L | 476 | 2.637 | 35 | **0.012** |

| Weather and monitoring method: Swell (PAM) | Median detection rate per hr *(+ 1st and 3rd quartiles)* | Friedman test | p-value | Pairwise comparisons | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Pair | $T^+$ | z | n | Adjusted p-value |
| 'Low' (0–2 m) (O) | *0.00* 0.01 *0.06* | $F_r$ = 1.563 | | | | | | |
| 'Medium' (2–4 m) (M) | *0.00* 0.01 *0.05* | n = 68 | > 0.05 | | | | | |
| 'Large' (> 4 m) (L) | *0.00* 0.00 *0.21* | d.f. = 2 | | | | | | |

| Weather and monitoring method: Visibility (visual monitoring) | Median detection rate per hr *(+ 1st and 3rd quartiles)* | Friedman test | p-value | Pairwise comparisons | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Pair | $T^+$ | z | n | Adjusted p-value |
| 'Poor' (< 1 km) (P) | *0.00* 0.00 *0.00* | $F_r$ = 344.151 | | P-M | 7,013.5 | 4.714 | 138 | **< 0.001** |
| 'Moderate' (1–5 km) (M) | *0.00* 0.00 *0.05* | n = 1,241 | **< 0.001** | P-G | 56,579 | 12.912 | 355 | **< 0.001** |
| 'Good' (> 5 km) (G) | *0.02* 0.05 *0.12* | d.f. = 2 | | M-G | 53,889.5 | 8.380 | 379 | **< 0.001** |

Although weather influenced visual detection, detection rates were higher for visual monitoring than acoustic monitoring. When comparing matched pairs where variables other than monitoring method were controlled for, visual monitoring resulted in significantly higher detection rates (at any range) than acoustic monitoring, for all cetacean species or species groups tested with the exception of sperm whale, for which the difference was not significant (Table 36). For animals in the mitigation zone, visual detection rates were higher than acoustic detection rates for all species except Atlantic white-sided dolphins (Table 37). In suboptimal sea conditions ('choppy' or 'rough' sea states or 'medium' or 'large' swell) visual detection rates were significantly higher than acoustic detection rates for all species or species groups able to be tested, although sample sizes for individual species were low (Table 37).

**Table 37.** Marine mammal detection rate in relation to monitoring method, tested using the Wilcoxon signed ranks test (z = Wilcoxon statistic; for small samples T+ = sum of ranks of pairs where sighting rate exceeded acoustic detection rate; n = sample size; P = probability). Significant results are in bold.

| **Species: At any range** | **Median detection rate per hour *(+ 1st and 3rd quartiles)*** | | | | | | **z** | **$T^+$** | **n** | **P** |
|---|---|---|---|---|---|---|---|---|---|---|
| | Visual monitoring | | | Acoustic monitoring | | | | | | |
| All cetaceans combined | *0.11* | 0.22 | *0.38* | *0.00* | 0.00 | *0.00* | 13.889 | - | 673 | **< 0.001** |
| All delphinids combined | *0.00* | 0.17 | *0.33* | *0.00* | 0.00 | *0.16* | 5.306 | - | 362 | **< 0.001** |
| Sperm whale | *0.04* | 0.11 | *0.21* | *0.00* | 0.00 | *0.05* | 1.643 | - | 20 | 0.05 |
| Long-finned pilot whale | *0.10* | 0.16 | *0.26* | *0.00* | 0.00 | *0.00* | 4.007 | - | 28 | **< 0.001** |
| White-beaked dolphin | *0.13* | 0.21 | *0.37* | *0.00* | 0.00 | *0.00* | 7.507 | - | 82 | **< 0.001** |
| Atlantic white-sided dolphin | *0.10* | 0.22 | *0.41* | *0.00* | 0.00 | *0.00* | 2.495 | - | 19 | **< 0.01** |
| Common dolphin | *0.13* | 0.17 | *0.52* | *0.00* | 0.00 | *0.00* | - | 28 | 7 | **< 0.01** |
| Harbour porpoise | *0.16* | 0.22 | *0.43* | *0.00* | 0.00 | *0.00* | 4.882 | - | 37 | **< 0.001** |

| **Species: Within the mitigation zone** | **Median detection rate per hour *(+ 1st and 3rd quartiles)*** | | | | | | **z** | **$T^+$** | **n** | **P** |
|---|---|---|---|---|---|---|---|---|---|---|
| | Visual monitoring | | | Acoustic monitoring | | | | | | |
| All cetaceans combined | *0.12* | 0.20 | *0.35* | *0.00* | 0.00 | *0.00* | 8.112 | - | 193 | **< 0.001** |
| All delphinids combined | *0.09* | 0.18 | *0.31* | *0.00* | 0.00 | *0.00* | 4.380 | - | 114 | **< 0.001** |
| Long-finned pilot whale | *0.09* | 0.12 | *0.18* | *0.00* | 0.00 | *0.00* | 2.940 | - | 18 | **< 0.01** |
| White-beaked dolphin | *0.13* | 0.24 | *0.41* | *0.00* | 0.00 | *0.00* | 5.192 | - | 41 | **< 0.001** |
| Atlantic white-sided dolphin | *0.17* | 0.25 | *0.36* | *0.00* | 0.00 | *0.00* | - | 28 | 8 | 0.10 |
| Harbour porpoise | *0.16* | 0.24 | *0.69* | *0.00* | 0.00 | *0.00* | - | 66 | 11 | **< 0.001** |

| Species: At any range in suboptimal sea conditions | Median detection rate per hour (+ 1st and 3rd quartiles) | | | | | | z | $T^+$ | n | P |
|---|---|---|---|---|---|---|---|---|---|---|
| | Visual monitoring | | | Acoustic monitoring | | | | | | |
| All cetaceans combined | *0.10* | 0.21 | *0.41* | *0.00* | 0.00 | *0.00* | 5.626 | - | 155 | **< 0.001** |
| All delphinids combined | *0.00* | 0.16 | *0.37* | *0.00* | 0.00 | *0.28* | 1.941 | - | 92 | **< 0.05** |
| Long-finned pilot whale | *0.10* | 0.19 | *0.31* | *0.00* | 0.00 | *0.00* | - | 21 | 7 | **< 0.05** |
| White-beaked dolphin | *0.15* | 0.23 | *0.40* | *0.00* | 0.00 | *0.00* | - | 120 | 15 | **< 0.001** |

| Species: Concurrent visual and acoustic monitoring | Median detection rate per hour (+ 1st and 3rd quartiles) | | | | | | z | $T^+$ | n | P |
|---|---|---|---|---|---|---|---|---|---|---|
| | Visual monitoring | | | Acoustic monitoring | | | | | | |
| All cetaceans combined | *0.74* | 1.17 | *2.58* | *0.00* | 0.00 | *1.00* | 5.245 | - | 100 | **< 0.001** |
| All delphinids combined | *0.00* | 1.03 | *2.14* | *0.00* | 0.00 | *1.03* | 3.407 | - | 66 | **< 0.01** |

There were 3,898 hrs 29 mins where visual monitoring and PAM were used concurrently, and effort records shared the same start and end times. Of 117 cetacean detections during these times, 79 were only detected visually, 17 were only detected acoustically and 21 were detected by both means. Of the 79 cases where cetaceans were only detected visually, 27 (34%) were animals that could reasonably be expected to be detected acoustically if they were vocalising (species vocalising at frequencies distinct from vessel noise and seen at a range where vocalisations would likely be detected: delphinids within 1 km, harbour porpoises within 300 m and sperm whales within 2 km). Of the 17 cases where cetaceans were only detected acoustically, four (24%) were of animals that could reasonably be expected to be seen (species with short dive times detected at relatively close range: delphinids within 1 km). Visual detection rates were significantly higher than acoustic detection rates for the combined groups of all cetaceans and delphinids (Table 37).

### 3.10.4 Detection rates of different PAM systems

Of the six different PAM systems used on geophysical surveys between 2011 and 2020, three were used more commonly. Of the three systems used most often, one had higher detection rates than the others, both overall and within the Central and Northern North Sea (Table 38).

**Table 38.** Detection rates of PAM systems.

| System | Mean detection rate per survey (± standard error) (detections per 100 hours) | | Number of surveys |
|---|---|---|---|
| **All areas:** | | | |
| A | 1.65 | (± 0.30) | 241 |
| B | 0.65 | (± 0.35) | 63 |
| C | 0.53 | (± 0.22) | 60 |
| D | 0.72 | (± 0.43) | 13 |
| E | 1.32 | (± 0.46) | 2 |
| F | 0.00 | (-) | 1 |
| **Central and Northern North Sea:** | | | |
| A | 0.92 | (± 0.27) | 131 |
| B | 0.21 | (± 0.17) | 26 |
| C | 0.58 | (± 0.28) | 43 |
| D | 1.35 | (± 0.89) | 6 |
| E | 0.86 | (-) | 1 |
| F | 0.00 | (-) | 1 |

### 3.10.5 Range estimation with PAM

There was no estimate of the range from the source for 56% of marine mammals detected only acoustically (compared to 15% with no range estimate for animals detected only visually). Range was more often estimated to a greater level of accuracy for visual detections than acoustic detections (Table 39). A greater proportion of acoustic detections were estimated to be at close ranges when compared to visual detections; 44% of acoustic

detections where range was estimated were thought to be within the mitigation zone, compared to 34% of visual sightings (Figure 17; Kolmogorov-Smirnov test: $\chi^2$ approximation = 24.445, d.f. = 2, $p < 0.001$).

**Table 39.** Minimum proportion of detections where the range was more detailed than to the nearest 100 m (for detections within 1 km) or nearest 500 m (for detections beyond 1 km) for animals detected by visual or acoustic means.

| Method of detection | Range up to 1 km from the source – proportion of range estimates more detailed than to nearest 100 m | Range more than 1 km from the source – proportion of range estimates more detailed than to nearest 500 m |
|---|---|---|
| Acoustic only | 23.6% | 29.7% |
| Visual only | 37.3% | 44.7% |

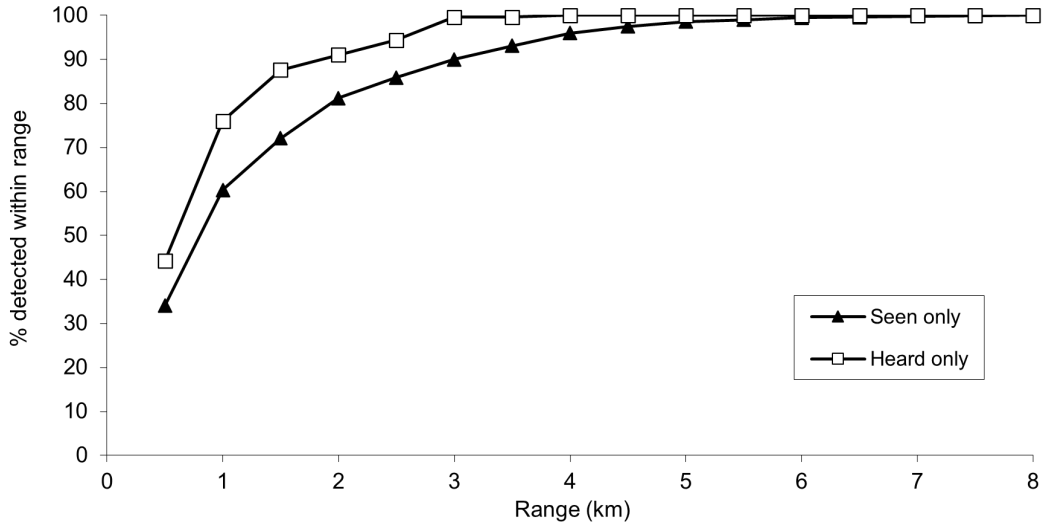


**Figure 17.** Proportion of detections of marine mammals within a given range of the source, for animals detected by visual means alone or by acoustic means alone (using only detections where range was estimated).

There were 17 occasions when marine mammals were detected only by acoustic means prior to operations commencing and there was no estimate of the range (16 on surveys with airguns and one on a high-resolution survey). On four (24%) of these occasions there was no attempt to delay although no explanation was given for not delaying; there was no indication that the PAM operator requested a delay.

## 3.11 MMOs and PAM operators

In the period from 2011 to 2020 there was an initial slight increase in the use of dedicated MMOs but numbers of dedicated MMOs per survey remained constant since 2013 (Figure 18). Numbers of PAM operators remained similar throughout the period; however, in earlier years, although fewer surveys used PAM those that did sometimes had higher numbers of PAM operators. Similar numbers of dedicated MMOs and PAM operators were used on high resolution surveys without airguns as on surveys with airguns (Figure 19).

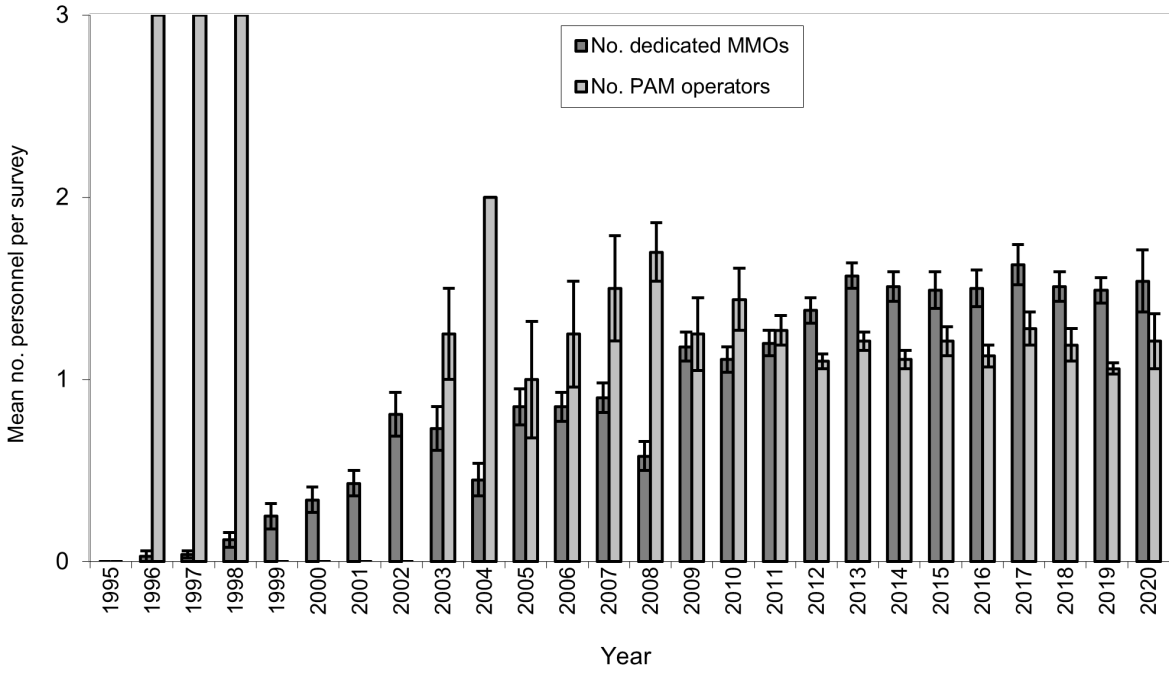


**Figure 18.** Mean number (and standard error) of dedicated MMOs (all surveys) and PAM operators (only surveys where PAM was used) per survey with airguns over time (UKCS only).

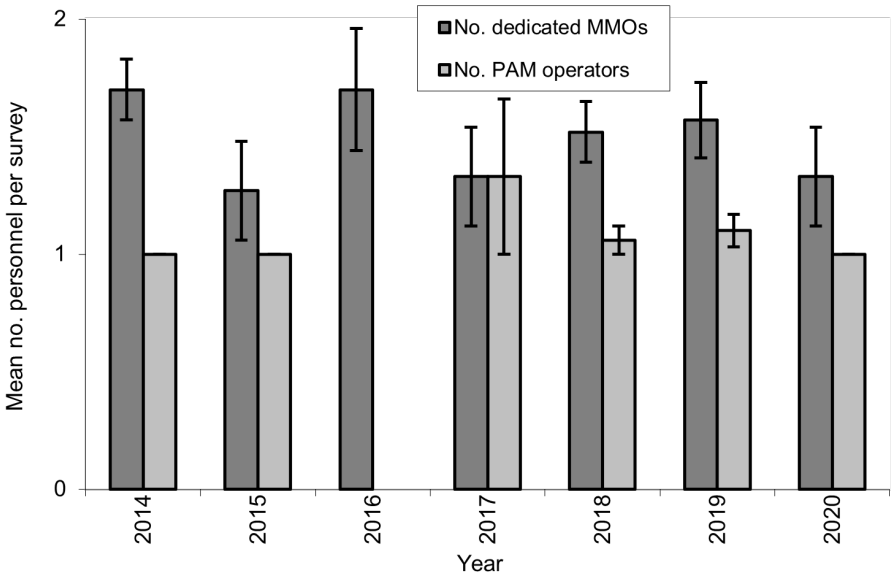


**Figure 19.** Mean number (and standard error) of dedicated MMOs (all surveys) and PAM operators (only surveys where PAM was used) per high resolution survey (without airguns) over time (UKCS only).

In the period between 2011 and 2020 VSPs were less likely to have dedicated MMOs than other survey types, and where PAM was used, they rarely had more than one PAM operator (Figure 20). Of 115 VSPs throughout the analysis period, 44 used a single dual role MMO / PAM operator; 18 of these occurred between 1 April and 1 October north of 57°N (during these months at these latitudes JNCC guidelines recommend that sufficient numbers of personnel are employed). Where a single dual role MMO / PAM operator was used this affected the ability to carry out pre-shooting searches as the single operative had to be available 24 hours and sometimes prioritised acoustic monitoring over visual monitoring during daylight (see section 3.9). Surveys with large airgun arrays (2D, 3D, 4D and OBS)

were more likely to have two dedicated MMOs, leading to a slightly higher mean number of MMOs per survey (Figure 20).

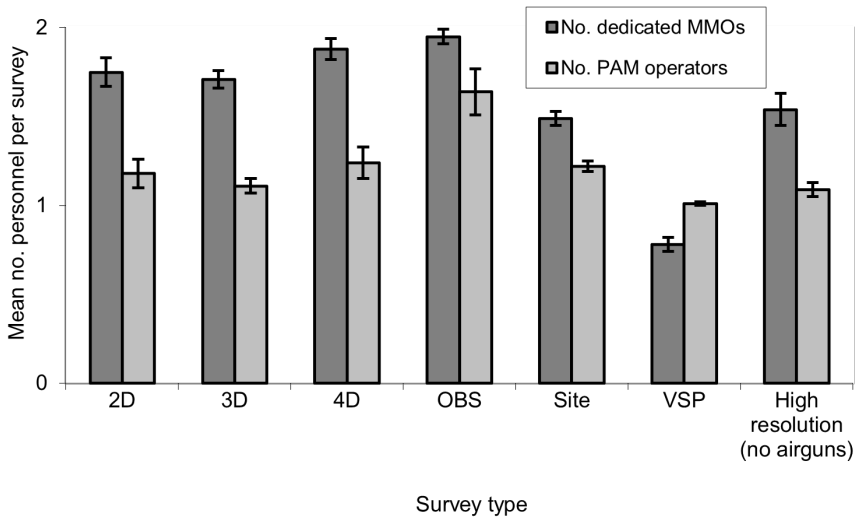


**Figure 20.** Mean number (and standard error) of dedicated MMOs (all surveys) and PAM operators (only surveys where PAM was used) per survey on different types of survey between 2011 and 2020 (UKCS only; high resolution surveys from August 2017 onwards only).

Use of PAM to complement the visual search during daytime appeared to be related to the number of PAM operators. Between 2011 and 2020, 61% of surveys with airguns where PAM was routinely used during the day had at least two PAM operators, while 92% of those mainly or only using PAM at night had just one PAM operator and 1% had no PAM operators. Most high-resolution surveys (without airguns) used PAM only at night; of these 91% had just one PAM operator.

Dedicated MMOs had higher sighting rates of marine mammals than non-dedicated MMOs and detected animals at greater distances (Table 40). Non-dedicated MMOs were more likely not to use binoculars for visual monitoring. Use of a rangefinder stick was the most common method of estimating distance (used on 49% of surveys), followed by reticle binoculars (23% of surveys). On a substantial proportion of surveys (22%) no tool was used to estimate distance to animals, with distance being judged by eye. This was more common for non-dedicated MMOs, who lacked any range-finding tool on more than half the surveys they were on. Compliance with pre-shooting searches and soft starts was similar regardless of whether MMOs were dedicated or non-dedicated, but delays were more often implemented correctly by dedicated MMOs. There were only two occasions when a delay was required when non-dedicated MMOs were used, but only one was implemented correctly.

**Table 40.** Observations and implementation of the guidelines by dedicated and non-dedicated MMOs on surveys within the UKCS, 2011–2020.

| | Dedicated MMOs | Non-dedicated MMOs |
|---|---|---|
| Sighting rate per 100hrs (all weather) | 3.28 | 0.58 |
| Sighting rate per 100hrs (good weather) | 4.55 | 0.53 |
| Median range of detection | 800m | 70m |
| Maximum range of detection | 8000m | 1600m |
| % surveys where no binoculars used | 1.4% | 5.2% |
| % surveys where no range finding tool used | 17.2% | 55.8% |
| % adequate pre-shooting searches during daylight | 95.1% | 94.5% |
| % soft starts meeting minimum required duration (all survey types) | 95.2% | 93.7% |
| % occasions when delays were correctly implemented | 87.5% | 50.0% |

Most surveys had data that was of sufficient quality to include in the database after checks and corrections were made, regardless of type of observer (Table 41). However, PAM operators often did not record weather conditions on the Effort form. Non-dedicated MMOs had few sightings, most of which did not have accompanying effort records.

**Table 41.** Quality of data recorded by dedicated MMOs, non-dedicated MMOs and PAM operators on surveys within the UKCS, 2011–2020.

| | Dedicated MMOs | Non-dedicated MMOs | PAM operators |
|---|---|---|---|
| % surveys where operations data were of sufficient quality to include in database | 95.0% | 93.9% | 94.2% |
| % surveys where effort data were of sufficient quality to include in database | 92.9% | 91.5% | 94.4% |
| % surveys where sightings data were of sufficient quality to include in database (where sightings / detections known to have occurred) | 97.3% | 89.5% | 100.0% |
| % effort records with full weather details recorded* | 97.0% | 99.3% | 38.3% |
| % effort records with no weather details recorded* | 0.0% | 0.1% | 42.7% |
| % sightings / detections with accompanying effort data | 80.5% | 36.4% | 84.9% |

* Excluding visibility and sun glare for PAM operators as they are not asked to record these.

## 3.12 Trends in operations

The median airgun volume for site, 2D, 3D, 4D and OBS surveys remained fairly constant, although the maximum volume was more variable, with peaks particularly in earlier years (Figure 21). There was a slight increase in the median volume of airguns used for VSP operations in recent years, although the maximum volume did not show a similar increase (Figure 21).

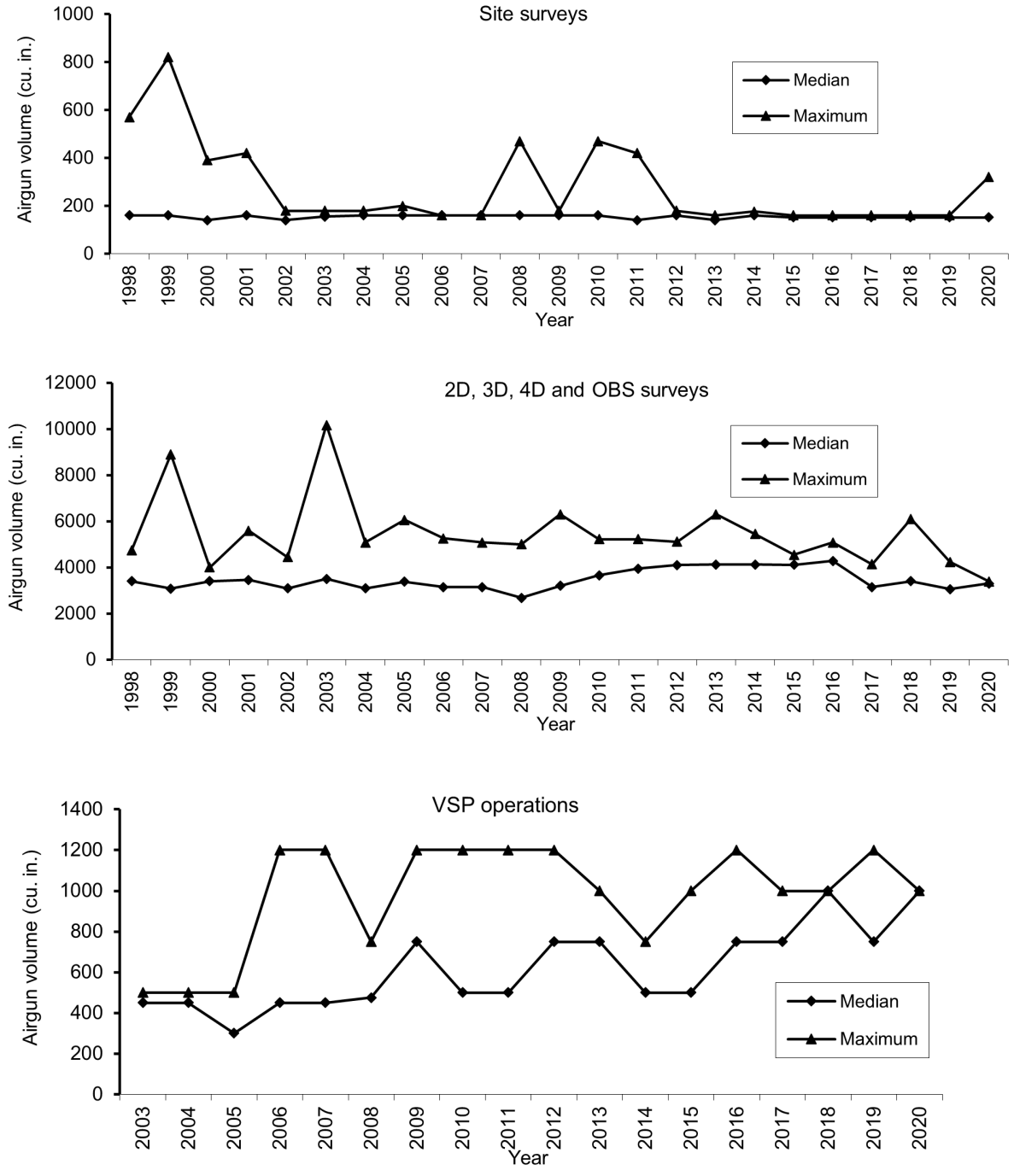


**Figure 21.** Median and maximum volume of airguns (cu.in.) per year (few data were available for VSP operations prior to 2003).

Most surveys with airguns between 2011 and 2020 were in the North Sea and around Shetland, with few in western and southern parts of the UKCS (Figure 22). There was a general decline in the number of surveys between 2011 and 2016, with a slight rise thereafter, although numbers declined again in 2020 (Figure 22). Very few reports were received from high resolution surveys without airguns prior to 2014. Most high-resolution surveys took place in the North Sea, with only two surveys in the Irish Sea and none in southern parts of the UKCS. Again, there was a slight decline until 2016 and a slight rise thereafter, but with numbers of surveys declining once more in 2020, most likely due to Covid-19 (Figure 23).

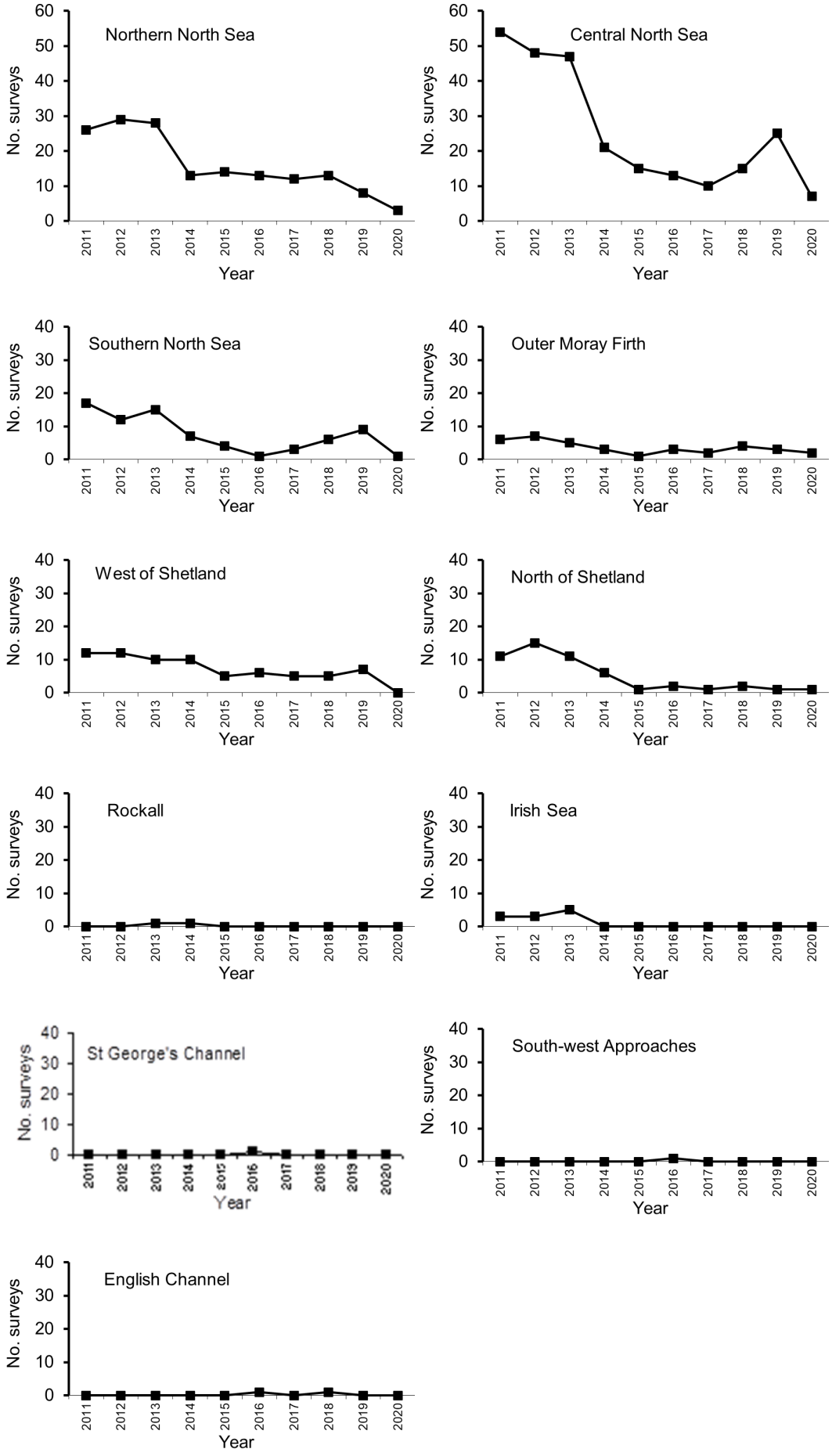


**Figure 22.** Number of surveys (with airguns) in different areas of the UKCS, 2011–2020.

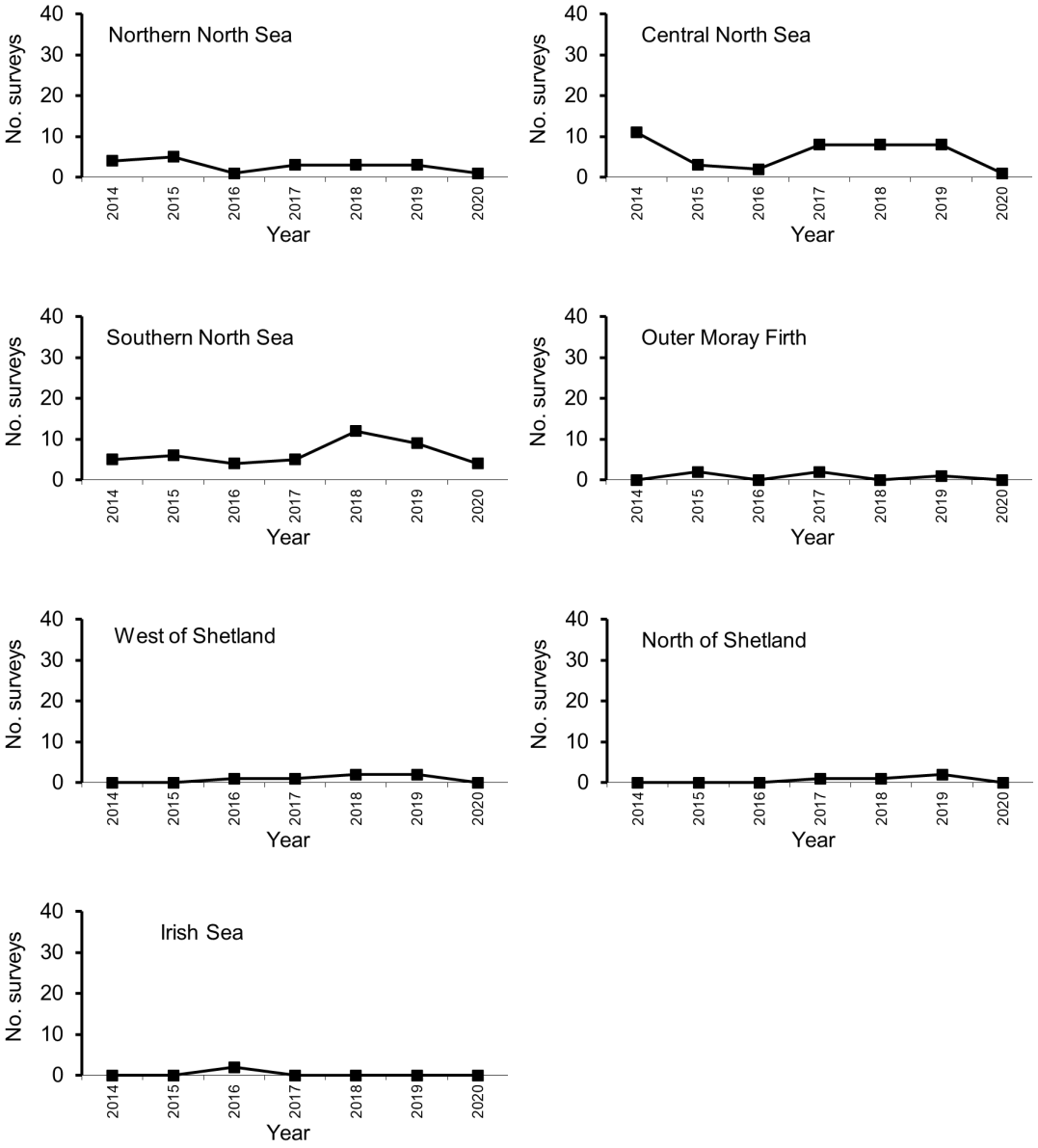


**Figure 23.** Number of high-resolution surveys (without airguns) in different areas of the UKCS, 2011–2020.

Most surveys took place during the summer months, except for VSPs where numbers of surveys were more constant throughout the year (Figure 24).

More consents were issued in the earlier years of the period between 2011 and 2020, with the lowest number of consents being in 2020 (Figure 25). Each year there were a number of surveys where there were no submissions of MMOs reports or data. Over the whole period, there was no submission of MMO reports or data for 31% of surveys consented; the proportion without a submission was highest in 2020 (Figure 25). Where there was a submission, in 10% of cases data were submitted with no accompanying MMO report, while in 4% of cases there was an MMO report with no accompanying data.

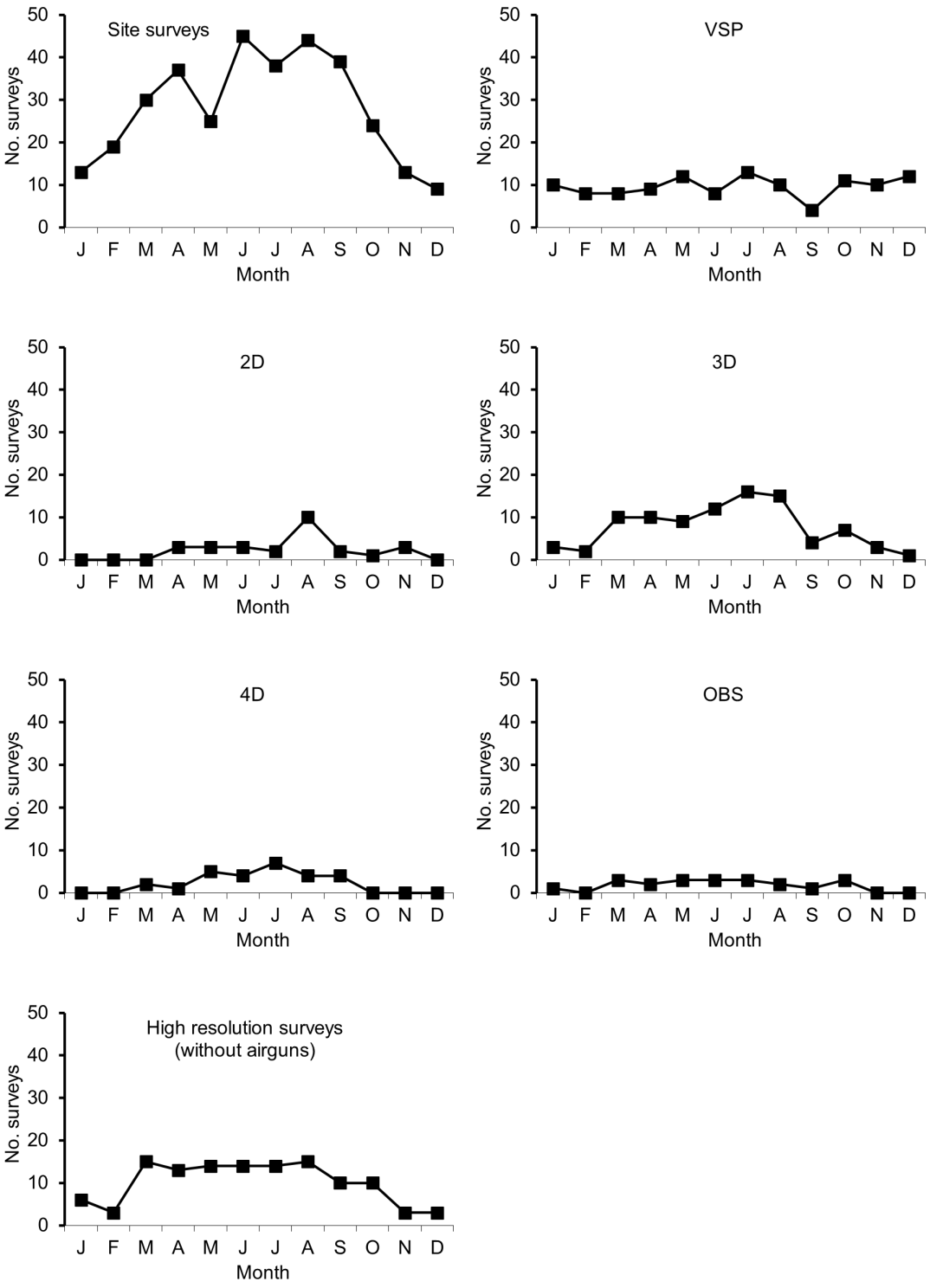


**Figure 24.** Seasonal variation of different survey types based on month of commencement of surveys in 2011–2020 (all years combined).

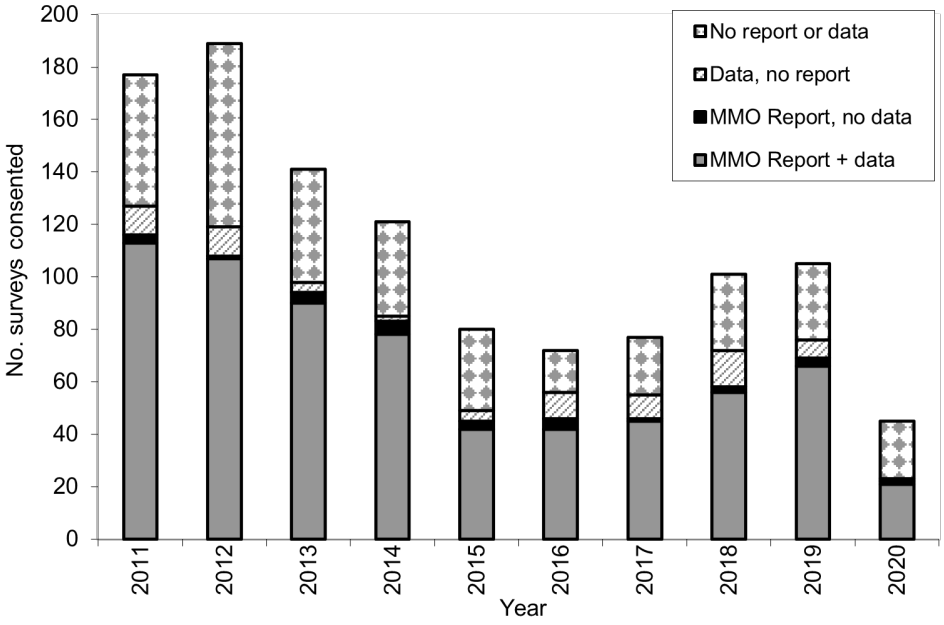


**Figure 25.** Number of geophysical surveys consented where MMO reports and/or data were or were not submitted (excluding surveys that were cancelled or where there was no submission, but the consent had not expired).

# 4 Discussion

## 4.1 Quality of data

Almost one third of geophysical surveys consented between 2011 and 2020 submitted no MMO report or data, despite the requirement to submit a report with completed Marine Mammal Recording Forms being included in conditions of consents for all O&G surveys. Although levels of compliance with the key mitigation measures in the JNCC guidelines were generally high for those surveys that did submit data, this needs to be considered in the context of the proportion of surveys for which data were submitted. The true level of compliance could potentially be lower.

Although most data that were submitted were of acceptable quality for inclusion in the database following checks and corrections, many mistakes were found. Less than half of surveys had Operations and Effort data that were assessed as being class 1. Many of the mistakes were of a nature that could have been avoided if MMOs and PAM operators thoroughly checked their own data and made appropriate corrections before submission.

Other issues arose from data being entered into something other than the standard JNCC Marine Mammal Recording Forms in Excel, whether an amended version of the forms or third-party software designed to populate the forms. Consents specify that the Marine Mammal Recording Forms should be used in their original format. As the use of other formats was associated with particular MMO / PAM operator providers rather than with specific MMOs and PAM operators, it seems likely that the providers directed their personnel to use the alternative formats. Consent holders may have been unaware that the original format was not being used. MMO / PAM operator providers should ensure that they do not make requests of their personnel that are contrary to the requirements of the consent.

One common issue that arose in recent years was the interpretation of the time the search / PAM ended (on the Operations form) as being the same as the time the soft start began, thus not demonstrating that the search had continued for the required period (at least until the start of line). Addressing this in training courses will only capture new MMOs. Should there be a requirement for periodic refresher courses in future then misinterpretations such as this could be addressed with existing MMOs. Training could also encourage PAM operators to record weather information; this was often lacking, limiting sample sizes for some aspects of analysis (e.g. controlling for weather when comparing detection rates).

Prior to 2017 the JNCC guidelines applied only to seismic surveys and most data was related to the use of airguns. Since the inclusion of high-resolution surveys in the guidelines in 2017, data relating to a few different sources have been collated. Currently the Marine Mammal Recording Forms require details of the source(s) to be included on the Cover Page, but there is no facility for distinguishing between different sources used at different times on the Operations, Effort or Sightings forms. Knowledge of the source active at any time is vital for analysis of compliance or response of marine mammals to noise. It is recommended that a field for specifying the source(s) is added to the Operations form.

Where reports were authored by someone other than the MMO or PAM operator there were cases where the details contained in the report had apparently been copied from previous reports and did not relate to the project in question. It is recommended that reports are written by the MMOs and/or PAM operators who will be fully familiar with the details of the project and are best placed to report on events.

## 4.2 The pre-shooting search

Compliant pre-shooting searches were assessed as those that met the required duration specified in the JNCC guidelines. However, the analysis did not consider the effectiveness of the pre-shooting search (i.e. the ability of the MMO or PAM operator to detect marine mammals). Analysis of 2011–2020 data showed that dedicated MMOs have higher detection rates than non-dedicated MMOs, while analysis of earlier data showed that dedicated MMOs with prior marine mammal experience have higher detection rates than those without (Stone 2015). Therefore, the use of dedicated, experienced personnel is recommended to maximise the effectiveness of pre-shooting searches.

Visual pre-shooting searches in daylight and acoustic pre-shooting searches at night generally lasted for the required duration, although there was still some room for improvement, particularly during the last two years and on VSPs in general. Where visual searches in daylight or acoustic searches at night were inadequate it was usually because they started late or finished prematurely, rather than there being no search. There was a much lower standard of compliance for acoustic pre-shooting searches in daylight, which were often absent in cases where the consent required them. In most cases where a required daylight acoustic search was absent there was only one PAM operator on board. If the consent requires that PAM is used to complement the visual search in daylight as well as being used at night or in low visibility it is important that operators provide enough personnel to achieve this.

As well as being linked to the absence of acoustic searches in daylight where required, insufficient staffing was also noted as a reason for inadequate visual pre-shooting searches in some cases. Although many cases where the pre-shooting search was inadequate were due to poor communication, unexpected issues arising or simply human error, those due to insufficient staffing could have been avoided with better planning. Operators should ensure they engage sufficient numbers of dedicated MMOs and PAM operators for their project.

Whilst only affecting a small number of cases, there were occasions where MMOs and PAM operators on surveys crossing between UK and Norwegian waters were not permitted to undertake any mitigation duties while in Norwegian waters. If the vessel was in Norwegian waters at the time when the pre-shooting search for a survey line in UK waters was due to begin this sometimes prevented an adequate search from being conducted. As with insufficient staffing, such non-compliances were, with better planning, avoidable. Operators of cross-border surveys should permit MMOs and PAM operators to commence pre-shooting searches outside of UK waters or alternatively ensure the design of the survey allows for a complete pre-shooting search within UK waters.

## 4.3 Delays in operations

Compliance with the requirement to delay commencing firing of the airguns for marine mammals in the mitigation zone improved from 2013 onwards compared to earlier years. Where procedures were not correctly implemented this was mostly due to there being no attempt to delay. Sometimes it seemed that there was a lack of awareness of current / planned operations, perhaps due to inadequate communication between MMOs / PAM operators and survey crew. However, on most occasions, delays were correctly implemented on surveys with airguns.

Although when high resolution surveys were first included in the guideline's compliance with the requirement to delay was relatively low, it did improve in subsequent years. Where correct procedures were not implemented it was often due to there being no soft start following a delay on surveys where the consent required a soft start. On these surveys there

was a lack of discussion with BEIS / JNCC regarding any difficulties of performing a soft start with the equipment being used. There is a greater need for companies operating these types of surveys to engage in discussions with BEIS / JNCC at the application stage for consents.

Although numbers of delays on high resolution surveys were low, they were required relatively more often than on surveys with airguns (1% of occasions when high resolution sources were used compared to 0.5% of occasions when airguns were used). This may reflect that some high-resolution surveys extend into waters further inshore (e.g. pipeline route surveys) where seals are often encountered. Almost half of the delays on high resolution surveys were for seals, whereas most delays in firing airguns were for dolphins.

There were some occasions where marine mammals were detected acoustically during the pre-shooting search and there was no estimate of the range. On almost one quarter of these occasions there was no delay, although no evidence was given that the animals were outside the mitigation zone. The guidelines could be amended to require a delay for all acoustic detections of marine mammals unless there is evidence that they are outside the mitigation zone.

Of particular concern was the one survey where there were attempts to deter an adult-juvenile pair of common dolphins from the mitigation zone, including the use of flares fired into the water in their vicinity. Although these dolphins persistently remained in the mitigation zone during the latter part of the survey, causing difficulties in completing the survey, such measures carry a high risk of injury, which for European Protected Species (including all cetaceans) is an offence under the Conservation of Offshore Marine Habitats and Species Regulations 2017. Furthermore, the disturbance offence in the regulations includes anything that might impair the ability of such animals to rear or nurture their young, which would be relevant in the case of this adult-juvenile pair. Such actions are therefore not justified in any circumstances.

The low number of occasions when delays were required when non-dedicated MMOs were used reflects the low detection rates with non-dedicated personnel. Compliance with the requirement to delay was also low for non-dedicated personnel. The use of dedicated MMOs is recommended both in terms of their ability to detect marine mammals that may be in the mitigation zone prior to operations commencing and compliance with the requirement to delay operations in such an event.

## 4.4 The soft start

For surveys with airguns, the majority of soft starts met the required minimum duration, particularly in recent years. On some site surveys earlier in the 2011–2020 period crews incorrectly applied the soft start exemption for a single mini-airgun to the use of two mini-airguns, but this happened less in recent years. The JNCC guidelines currently define a mini airgun as being a single airgun with a maximum volume of 10 cu.in.; in data analysis a single airgun with a volume of 12 cu.in. was also treated as a mini airgun. As there is little difference in the operation of a single 10 cu.in. or 12 cu.in. airgun it would be appropriate for the guidelines to include a single airgun of up to 12 cu.in. within the definition of a mini airgun.

The increasing frequency method of soft start ceased to be listed as a recommended method in the August 2017 revision of the guidelines, but nevertheless continued to be used since then, particularly on-site surveys which use small airgun arrays. When this method is used, the first shot of a soft start is at the full operational volume therefore the soft start commences at the same source level as full power. This carries a greater risk of injury to marine mammals so increasing the number of airguns or increasing the pressure, whereby

the initial source level is reduced, are the preferred methods. However, the guidelines do not explain this risk, instead simply omitting the increasing frequency method from the example methods listed. It may be worth actively discouraging the use of this method, particularly for airguns where there are viable lower-risk alternatives.

Since August 2017 shorter soft starts have been permitted for airgun arrays with a maximum volume of 180 cu.in. (minimum duration of 15 minutes from commencement of the soft start until full power; maximum duration of 25 minutes from commencement of the soft start until the start of the survey line). While almost 100% of soft starts of small arrays since then have met the required minimum duration, there was a decrease in compliance with the maximum duration following this revision. However, compliance with the maximum duration showed progressive improvement in 2019 and 2020 although by 2020 had not yet returned to the standard attained before the guideline revision.

There could be several reasons why compliance with the maximum soft start duration for small arrays has declined since the 2017 revision:

1) lack of awareness of the revised duration;
2) difficulties in applying the revised criteria;
3) lack of clarity in consents.

Improvements in 2019 and 2020 might suggest that a lack of awareness contributed, at least in part. Although no reports commented on difficulties of applying the revised soft start criteria, the difference between the minimum and maximum permitted durations of soft starts for small arrays, currently just 10 minutes, is less than for larger arrays where there is a 20-minute difference between the minimum and maximum permitted durations. Potentially there could be difficulties in timing a soft start to reach full power with only 10 minutes leeway, especially in areas where tides or currents may influence the speed of the vessel. Additionally, the wording of consents for some surveys did not match the measures noted in the JNCC guidelines, often requiring a minimum soft start duration of 20 minutes (regardless of array size) and not noting a maximum duration; although consents also stated “Further information can be found in the JNCC guidelines”, this could have caused some confusion. Aiming for a 20-minute minimum duration as noted in the consent would also make it more difficult to achieve the maximum 25-minute duration in the guidelines. Better agreement between consents and the guidelines and further assessment of compliance with the maximum soft start duration for small arrays is needed in future years to establish the reason for the decline in standards and whether it represents real difficulties in complying with the shorter maximum permitted duration or not.

VSPs also sometimes had excessively long soft starts, perhaps indicating a need for more accurate estimation of the time of the start of data acquisition by crews on these operations so that the soft start does not begin too far in advance.

Where issues arose with the timing of the soft start these were often due to circumstances arising at the time (e.g. currents affecting vessel speed, technical issues, human error, etc.). However, on some surveys the greater working area delineated in the application for consent was not sufficient to allow for a full soft start, resulting in either the soft start being too short or shooting taking place outside the consented area. The guidelines emphasise that pre-shooting searches and soft starts should be incorporated into the survey design so any greater working area specified in applications for consent should include any areas where soft starts will be needed.

In earlier years it was found that spare airguns were being fired during the soft start in addition to the other airguns in large arrays, resulting in the volume firing at the end of the

soft start being greater than the production volume (Stone 2015). This often continued to be the case since 2011 on those surveys where the progression of soft starts was recorded. The August 2017 revision of the guidelines specified that airgun firing must not exceed the planned maximum production volume outlined in the application for consent, but no reports since then have given details of the progression of soft starts on surveys with large airgun arrays, so it was not possible to determine whether this practice has stopped or continues. It is recommended that MMO reports include details of the progression of the soft start.

Compliance with the requirement to perform a soft start was poor on high resolution surveys until 2020. Often there was no soft start, even though it was required as a condition of consent. It appears that for many of these surveys there was little or no discussion with BEIS / JNCC regarding difficulties of performing a soft start.

## 4.5 Breaks in operations

There were two areas where compliance with the requirement for monitoring during short breaks in operations (less than 10 minutes) prior to resuming at full power was low: breaks at night (where there was sometimes a lack of monitoring with PAM) and breaks on high resolution surveys (when there was often no monitoring during the break). For breaks at night or during conditions not conducive to a visual search the guidelines say that monitoring should be done with PAM and if PAM is not available then the survey must be delayed until conditions are suitable for visual observations. For short breaks of less than 10-minutes, if PAM arrays are not already deployed it is unlikely that they could be deployed within this period, however it seemed that at least in some cases firing resumed with no delay to allow monitoring beforehand. Although there was often no monitoring during short breaks on high resolution surveys, most of these breaks occurred during one survey, so may not be representative of industry practice.

## 4.6 Source testing

The guidelines say that where feasible, airgun tests should be incorporated into the soft start procedure and conducted before the start of a survey line to reduce the total amount of noise being introduced into the marine environment. However, most tests were conducted separately from survey lines. On some surveys testing was excessive, including one survey when there were more tests than survey lines. On high resolution surveys, sometimes there was no soft start and source testing commenced at full power even where the consent required a soft start. As with survey lines, the requirement for a soft start on high resolution surveys was sometimes ignored without discussion with BEIS / JNCC.

## 4.7 Line change

Compliance with the time limits for continued airgun activity during line changes improved following the revision of the JNCC guidelines in August 2017, when the time limit was changed to 40 minutes regardless of the size of the array (previously there was a 20-minute limit for large arrays ≥ 500 cu.in., which proved difficult to implement on OBS surveys).

Surveys with high resolution sources (excluding airguns) often continued activity during short line changes and compliance with time limits was generally good; however, there were some surveys where sub-bottom profilers were used simultaneously with airguns and although the airguns stopped during longer line changes the sub-bottom profilers continued to be active, sometimes for prolonged periods. Crews should ensure that if the line change is expected to take more than 40 minutes, all acoustic sources are stopped.

One reason for allowing firing to continue during short line changes is because of potential difficulties performing a full soft start within the time available. However, for the use of a single mini airgun there is an exemption from having to perform a soft start. On surveys using a single mini airgun, continued firing during short line changes (although currently permitted under the guidelines) represented a significant increase in overall noise input to the marine environment. As a soft start is not required it would be feasible to stop firing and undertake a pre-shooting search (and delay if necessary) before the next survey line. This may also be applicable to any high-resolution sources where a soft start is not possible. Such an approach would have the benefit of reducing overall noise input to the marine environment, but the potential risk of injury to undetected marine mammals from commencing without a soft start (detected animals being protected by delaying activity) would need to be considered (although it should be remembered that firing a mini airgun is equivalent to the beginning of a soft start on many larger arrays). Continued activity during short line changes may have a deterrent effect and thus reduce the risk of injury but increases noise overall.

In some other jurisdictions (e.g. Australia, Canada and formerly the Gulf of Mexico) the use of a 'mitigation gun' (also sometimes known as minimum source) is permitted during line changes of any duration. There have been some occasions in previous years where a 'mitigation gun' has been improperly used for prolonged periods in the UKCS (Stone 2015). In 2011–2020 there continued to be a few surveys where this practice was adopted on some occasions, usually without permission from BEIS / JNCC. Only on a minority of such occasions was it recorded that the MMOs / PAM operators advised against this. Analysis of MMO data from the Gulf of Mexico has found indications that whales may remain close to the surface during use of a minimum source, potentially affecting feeding (Barkaszi & Kelly 2019). JNCC guidelines do not permit the use of a 'mitigation gun' for prolonged periods; mitigation personnel should ensure that they provide appropriate advice on the mitigation measures included in JNCC guidelines to crew who may be more familiar with measures used elsewhere.

## 4.8 VSP operations

In earlier years there was confusion about what to do when repositioning geophones on VSP operations (Stone 2015), with crews often deciding to fire a 'mitigation shot' at nine-minute intervals, sometimes for a prolonged period. By 2011 this practice had become commonplace on VSPs and was noted in several MMO reports up until 2016. In the 2017 revision of the JNCC guidelines it was clarified that repositioning geophones should be treated like a line change and firing could continue if repositioning was expected to take less than 40 minutes, at a maximum shot interval of five minutes. However, reports since 2017 have often lacked the detail needed to assess compliance. Several reports noted using 'mitigation shots' but only one recorded the shot interval, this being nine minutes. Usually, the duration of repositioning was not recorded, although where it was, continued firing exceeded the permitted duration more often than for line changes on other survey types. Although some reports alluded to some difficulties in complying with the guidelines, currently there is insufficient evidence to assess the true level of compliance and whether the procedures for repositioning in the guidelines are appropriate.

Over one third of VSPs had a single dual role MMO / PAM operator. The use of a single person performing both roles led to PAM being used as a substitute for a visual pre-shooting search in daylight on some occasions, usually with no justification given. On over one fifth of occasions a visual pre-shooting search was absent during daylight when a dual role MMO/ PAM operator was used. It is recommended that use of a single person to perform both the MMO and PAM operator role is not permitted.

## 4.9 Passive Acoustic Monitoring

There was increasing use of PAM on surveys throughout the 2011–2020 period; by the end of the period almost all surveys with airguns and most high-resolution surveys used PAM.

There was increasing use of PAM to monitor for marine mammals prior to operations commencing at night; by 2020 there were no occasions on any surveys when operations commenced at night without PAM (although occasionally the monitoring was not of the required duration). However, there was often no acoustic search to complement the visual search in daylight on surveys where this was required in the consent; in many of these cases there was only one PAM operator on board.

There was increasing use of PAM in suboptimal or very poor weather conditions, but this was sometimes as a substitute for a visual search in daylight rather than to complement it, including on some occasions when there were enough mitigation personnel on board to do both. Visual detection rates in suboptimal sea conditions were similar or significantly higher than acoustic detection rates. Although sample sizes did not permit statistical testing for very poor weather conditions, most detections in these conditions were visual. As PAM has not been demonstrated to be more effective than visual monitoring on geophysical surveys in suboptimal / very poor conditions it is recommended that using PAM as a substitute for a visual search in daylight may not always be appropriate, particularly if the issue is with sea conditions rather than visibility. If there are enough personnel both monitoring methods should be used together in suboptimal / very poor conditions in daylight to increase the chance of detecting marine mammals. Using both methods is particularly beneficial in very poor conditions ('rough' sea states or 'large' swell), as visual detections decline in such conditions. However, if the number of personnel is such that a choice of monitoring method in daylight must be made, then it is recommended visual monitoring should be used unless visibility is restricted to the extent that the mitigation zone cannot be seen, in which case PAM should be used. During increased sea states or swell in daylight it is recommended that PAM is only used in addition to, and not as a substitute for, visual monitoring.

Analysis of concurrent visual and acoustic monitoring offers the most robust comparison of their effectiveness for detecting marine mammals for mitigation purposes. Visual detections were more prevalent than acoustic detections, as was also found to be the case on seismic surveys in New Zealand (Childerhouse *et al.* 2016). Conversely, in the Gulf of Mexico acoustic detection rates in some years have exceeded visual detection rates, particularly for dolphins, although what constitutes an acoustic detection is poorly defined and some PAM operators were noted as recording hundreds of detections over a short period (Barkaszi & Kelly 2019). Visual monitoring and PAM each have their own strengths and weaknesses (Verfuss *et al.* 2018) and different behaviours by individuals and species may render them more available for detection by one or other method. Only animals at the surface will be available for visual detection, while only animals vocalising will be available for acoustic detection. Furthermore, overlap between the frequencies of vocalisations and background noise (ship noise, flow noise) can limit detection of baleen whales and seals using towed hydrophone arrays (Verfuss *et al.* 2018; Prawirasasra *et al.* 2019), while detection range of high frequency harbour porpoise clicks is only around 300 m (Cucknell *et al.* 2016).

Most of the marine mammals detected on UK geophysical surveys between 2011 and 2020 were detected by only one method (either because the other method was not being used at the time or because the animals were not detected by the other method). Although there were more visual detections than acoustic detections (both in terms of absolute numbers of detections and numbers per unit effort), the use of PAM enabled some animals to be detected that would otherwise not have been. Continued use of PAM is therefore beneficial, either alongside visual monitoring to increase the chance of detecting marine mammals, or in conditions when visual monitoring is not possible (e.g. during hours of darkness).

Although most delays were due to visual detections, across all survey types during the 2011–2020 period there were 30 delays due to acoustic detections where animals would otherwise have been undetected.

Range estimation was often difficult with PAM and there was an inconsistent approach regarding whether to delay if marine mammals were detected acoustically during the pre-shooting search and there was no estimate of the range. There were 13 occasions when delays were implemented for acoustic detections where there was no estimate of the range, but for a further four such detections there was no delay. These four instances were not included in the assessment of compliance as it is possible they were outside the mitigation zone, but no justification was given for not delaying. It is recommended that, in the absence of evidence that marine mammals are outside the mitigation zone, there should be a precautionary delay.

Between 2011 and 2020 a greater proportion of acoustic detections were within the mitigation zone compared to visual detections (although visual detection rates in the mitigation zone were higher than acoustic detection rates). However, in earlier years the opposite was true (Stone 2015). The reason for this difference is not clear.

Differing detection rates with the various PAM systems used may reflect differing capabilities or may reflect differences in the surveys they were deployed on, for example detection rates being higher on surveys taking place in areas and seasons of high cetacean abundance. Although there were differences in detection rates between systems when considering only the Central and Northern North Sea, surveys in these areas still varied widely in their location and timing. In addition, varying challenges in deployment of the hydrophone arrays between vessels may have influenced the results. As different systems are not used side by side on the same survey, it is not possible to make an accurate comparison of the systems using the PAM data from geophysical surveys. Nevertheless, the differences seen in detection rates between systems suggest that further studies are needed. An independent assessment of the capabilities of the different systems being used, and their effectiveness at monitoring for marine mammals during geophysical surveys, would be worthwhile.

## 4.10 MMOs and PAM operators

There were some surveys where insufficient numbers of personnel were used. In particular, the number of PAM operators influenced the use of PAM in daylight. For surveys where the consent required that PAM was used to complement the visual search in daylight there was often no daylight acoustic search; in most of these cases there was only one PAM operator on board even though the consent required monitoring with PAM both at night and in the day. Only a minority of surveys, often those with two PAM operators, used PAM routinely to complement visual observations in daylight.

Fewer personnel tended to be used for VSPs, with sometimes only a single dual role MMO / PAM operator. This was sometimes even the case in seasons / locations where daylight hours are long and the JNCC guidelines emphasise the importance of engaging sufficient personnel. The use of a single person compromised the ability to monitor for marine mammals and sometimes there was no visual pre-shooting search in daylight. To improve standards on VSPs and on surveys where acoustic monitoring is required alongside visual monitoring in daylight it is recommended that operators of surveys ensure that they engage sufficient personnel to enable compliance with both the JNCC guidelines and survey specific consent conditions.

Dedicated MMOs performed better than non-dedicated MMOs in terms of their ability to detect marine mammals. Non-dedicated MMOs were sometimes poorly equipped, particularly regarding tools to estimate the range to animals. Although compliance with pre-

shooting searches and soft starts were generally good for both dedicated and non-dedicated MMOs, there were only two delays due to the presence of marine mammals when non-dedicated MMOs were used and only one was implemented correctly.

It would be beneficial if PAM operators recorded weather conditions during monitoring. Although the recording forms do not require visibility or sun glare to be recorded by PAM operators (as these will not influence the number of detections), other weather conditions should be recorded but often were not. Inclusion of weather conditions facilitates analysis, for example by controlling for the influence of weather when analysing detection rates.

## 4.11 Long-term trends in compliance and areas for improvement

Although during the 2011–2020 period there were still some areas where compliance could be better, the overall long-term trend compared with earlier years is of improvement. Compliance with key mitigation measures (visual pre-shooting searches in daylight or acoustic pre-shooting searches at night, delaying operations for marine mammals in the mitigation zone, conducting a soft start of a minimum duration) has, for the most part, steadily improved over the years where data are available for assessment. For some mitigation measures (e.g. soft starts meeting the minimum duration) compliance had already reached high levels prior to 2011 and remained high since, while for others (e.g. adequate pre-shooting searches and delays) there was continued improvement at the beginning of the ten year period. By 2013 there was generally good compliance with all key mitigation measures, although there was a slight decline in the standard of visual pre-shooting searches in 2019 and 2020.

Areas where there is still scope for improving compliance tend to be survey specific, relating either to the type of survey or type of source, or consent conditions for individual surveys. Such areas include:

- use of an acoustic pre-shooting search in daylight when required by consent
- improving standards of pre-shooting searches on VSPs
- providing adequate pre-shooting searches on cross-border surveys
- not exceeding the maximum duration for soft starts of small airgun arrays
- use of a soft start for high resolution sources (or discussion with BEIS / JNCC where this is not possible)
- not using the increasing frequency method of soft start for airguns on site surveys
- not applying the soft start exemption for a single mini-airgun to two mini-airguns on site surveys
- providing monitoring during short breaks in operations on high resolution surveys
- use of acoustic monitoring during short breaks in operations that occur at night.

Another area where there is a need for improved compliance, which is not survey specific, is in the submission of MMO reports and data. The lack of a report and data for many surveys brings into question application of mitigation on those surveys.

Since the August 2017 revision of the guidelines there has been a trend towards a lack of detailed information when reporting some areas where the revision addressed questionable practices highlighted previously in analysis. Further information on current practices is needed to assess whether the 2017 revision of the guidelines adequately addressed these issues or whether poor practices remain.

These areas are:

- procedures during repositioning of geophones on VSPs
- the progression of the soft start for large airgun arrays.

## 4.12 Considerations for future revisions to the guidelines

Some areas where compliance could be improved are already clearly addressed in the guidelines (e.g. exemption for soft starts only applying to a single mini-airgun, needing to monitor with PAM during short breaks in operations at night, the requirement to submit a report and data after completion of the survey, etc.). In some cases, there is simply a requirement for operators of certain survey types to ensure that they do comply with the mitigation measures (e.g. avoiding prolonged soft starts on VSPs, monitoring during short breaks on high resolution surveys, not keeping high resolution sources active during longer line changes after airguns have been stopped, etc.).

For some surveys better consideration of the existing requirements of the guidelines during the planning stage would lead to improved compliance. Although consents do not usually specify numbers of mitigation personnel, the guidelines emphasise that there should be adequate staffing, noting that it is the operator's responsibility to employ sufficient MMO / PAM personnel. Better consideration during planning regarding the number of personnel needed to fulfil the mitigation obligations within consents and the guidelines would lead to improved compliance for pre-shooting searches, particularly for VSPs and for acoustic searches when required in daylight. Similarly, the guidelines note that pre-shooting searches and soft starts should be incorporated into the survey design, yet for some surveys the greater working area delineated during planning did not allow adequate space for a soft start of the required duration. The guidelines also advise that if high resolution sources are used where it will not be possible to perform a soft start this should be highlighted during any application for consent (i.e. at the planning stage), yet it seemed that in some cases this was only noted in the MMO report after the survey. None of these areas require changes to the guidelines, but rather that more attention is paid to the existing requirements therein.

There are some aspects of the guidelines where changes may be required in future but currently there is insufficient information to assess whether a change is needed. From the available data, compliance with procedures for repositioning geophones on VSPs, although not poor, was lower than compliance with the equivalent procedures for line changes on other survey types. However, the lack of detail in MMO reports and data from many VSP operations in recent years makes it difficult to assess what, if any, changes might be needed. It is recommended that the existing measures for repositioning geophones remain, whilst being open to review in future should further evidence emerge.

Similarly, it is recommended that the existing minimum and maximum soft start durations for small airgun arrays remain, whilst being open to review subject to further evidence. Depending on compliance in future years, there may be a need to revise the maximum soft start duration for small arrays. If there is a need to amend the maximum duration, then 30 minutes (from the beginning of the soft start until the start of line) might be appropriate. Examination of the data found that if the maximum permitted soft start duration for small airgun arrays had been 30 minutes (from the beginning of the soft start until the start of line) compliance with this criterion since August 2017 would have been 96%. However, it is possible that the decline in compliance with the maximum soft start duration subsequent to the existing criteria for small arrays being introduced in 2017 may not have been due to practical difficulties, but due to lack of awareness or discrepancies between consents and the guidelines. Therefore, this should remain open to review.

There are some areas where additional clarification in the guidelines may be beneficial. Although the guidelines permit the use of dual role MMO / PAM operators, there could be further clarification that the use of a single dual role MMO / PAM operator is unsuitable when both visual observations and PAM are required. Whilst it is acceptable for multiple personnel to switch between roles, it is not acceptable to expect a single person to be available over a 24-hour period. Discontinuing the use of a single dual role MMO / PAM operator should improve standards of pre-shooting searches on VSPs.

The guidelines currently say that it is not recommended that PAM is used as the sole method of mitigation during periods when visual searches are possible. However there has often been a belief that PAM is more effective at detecting marine mammals than visual monitoring during suboptimal weather conditions, hence it has sometimes been used as a substitute for visual monitoring in daylight, with differing interpretations of when this might be justified. In the light of the results presented here there should be clarification in the guidelines or in consents regarding the use of PAM in daylight. Whilst it is always a useful addition to visual monitoring, it should not be used as a substitute for visual monitoring except during hours of darkness or in restricted visibility such that the full extent of the mitigation zone cannot be seen. It should be made clear that restricted visibility does not include increased sea conditions. In increased sea conditions, both visual monitoring and PAM should be used if there are enough personnel available, but if there is only scope for using one method then visual monitoring should be used. This should be open to further review in future should there be evidence that the effectiveness of PAM for detecting marine mammals during geophysical surveys has increased.

Although the guidelines require a delay for all marine mammals detected in the mitigation zone during the pre-shooting search, whether by visual or acoustic means, there is currently no guidance on what to do if a marine mammal is detected acoustically and there is no estimate of the range, so it cannot be determined whether the animal is in the mitigation zone or not. On most occasions when this happened there was a delay, but there were some occasions where there was no delay and there was no indication that the PAM operator requested one. It is possible that PAM operators might feel uncomfortable requesting a delay if they do not have evidence that the animal is in the mitigation zone. It is suggested that the guidelines should adopt a precautionary approach and recommend a delay for any acoustic detection of a marine mammal during the pre-shooting search unless there is evidence that the animal is outside the mitigation zone. As well as providing protection for marine mammals, this would also provide clarification for PAM operators who may be unsure of the best approach in this situation.

Increasing the frequency of shots (i.e. decreasing the shot interval) is no longer listed as a method of performing a soft start in the guidelines, but site surveys with small airgun arrays often continue to use this method, where the initial shot is at the same source level as full power. There are viable lower-risk alternatives for performing a soft start with airguns, where the source level is reduced initially. It may be worth clarifying in any future revision of the guidelines that all airgun soft starts should have a progressive increase in source level (dB re. 1 µPa or bar metres) and that increasing the frequency of shots on its own is to be avoided as a method. For some high-resolution sources increasing the repetition rate may be the only option for conducting a soft start but should also be avoided if there is a better alternative (e.g. increasing the power).

The guidelines currently define a mini airgun, for which there is an exemption from having to perform a soft start, as a single airgun with a maximum volume of 10 cu.in. As the use of mini airguns with a volume of 12 cu.in. has become common in recent years, it is recommended that this definition is amended to a single airgun with a maximum volume of 12 cu.in. However, it could be clarified that where two or more mini airguns are used together there should be a soft start.

There should be consideration of whether a single mini airgun should remain active during short line changes, as is currently permitted, or whether it should be stopped and a pre-shooting search (and delay if a marine mammal is in the mitigation zone) conducted prior to the next survey line. Stopping firing during all line changes for a single mini-airgun should be achievable (as a soft start is not required for a single mini-airgun) and would reduce overall noise input to the marine environment. However, the reduction in overall noise would need to be balanced against the potential risk to marine mammals should they approach the source when it is inactive during the line change and not be detected prior to firing resuming. It should also be considered in relation to the increased requirement for monitoring that this approach would entail. The same should be considered for any high-resolution sources where a soft start is not possible.

In the section of the guidelines on reporting, it would be useful to request that MMO reports include details of the progression of the soft start, such as the number and volume of airguns firing at different stages. There should also be a requirement that if there is any agreement with BEIS / JNCC regarding exemptions or variations from the procedures outlined in the JNCC guidelines or consent, that documentary evidence of such agreement (e.g. copies of emails) is submitted with the report. The guidelines should recommend that MMO reports are authored by the MMOs and/or PAM operators who were on board.

MMOs and PAM operators should be encouraged to check their data on the Marine Mammal Recording Forms thoroughly prior to submission, including cross-checks between the individual forms. There could be a recommendation to this effect within the section on reporting.

There were some discrepancies between conditions of consents and the mitigation measures included in the JNCC guidelines. While conditions of consent almost always referred to the guidelines for further information, apparent differences between the two sometimes led to confusion with MMOs and PAM operators being unsure of the correct procedures to follow. The differences that have caused the most confusion have been those relating to breaks in operations and the duration of the soft start for smaller airgun arrays. It is recommended that consent conditions more closely match the requirements of the guidelines and that where survey specifics justify a variation within the consent that this is clearly highlighted as such so that MMOs and PAM operators can be confident that the difference is intended.

## 4.13 Considerations for future revisions to the recording forms

As some surveys use multiple sources either singly or in various combinations at different times, there is a need to distinguish in the data which source(s) were used at any given time. It is recommended that a field for specifying source(s) is added to the Operations form. Although during analysis this is also required for Effort and Sightings data, this can be added during the quality control process using the information from the Operations form.

# 5 Conclusions

Submission and review of MMO / PAM data is vital for gaining an overview of mitigation applied during geophysical surveys to reduce the risk to marine mammals. Assessment of compliance not only provides assurance that mitigation is applied, but also enables identification of any areas where mitigation procedures may need to be reviewed.

This analysis of data from 2011–2020 complements the previous analysis of earlier data (1995–2010, Stone 2015), together enabling long-term trends to be evaluated. The overall long-term trend is of improvement in compliance, but there are some specific areas where further improvements are needed. These areas include: performing adequate pre-shooting searches on VSP operations; conducting an acoustic pre-shooting search in addition to the visual search in daylight where this is required in the consent; not exceeding the maximum permitted soft start duration for small airgun arrays; conducting a soft start with high resolution sources (or discussing any difficulties with BEIS / JNCC); monitoring during short breaks in operations at night or on high resolution surveys; not keeping high resolution sources active during longer line changes when airguns have stopped; and submitting MMO reports and data.

Because of some of the findings from this analysis, some suggestions are made for clarifications to the JNCC guidelines for geophysical surveys. These include: not using a single dual role MMO / PAM operator; requirements for delays in commencing operations to include any acoustic detection where range cannot be estimated; not using PAM as a substitute for (although it may be used in addition to) visual monitoring in increased sea conditions in daylight; requiring soft starts to use methodology where there is a progressive increase in source level (dB re. 1µPa or bar metres); requesting details of the progression of soft starts in MMO reports; amending the definition of a mini airgun; recommending that MMO reports are authored by the MMOs and/or PAM operators involved; requiring the MMO report to contain documentary evidence if there are agreements for exemptions / variations from procedures in the guidelines or consent; and encouraging MMOs and PAM operators to check their data.

# References

Barkaszi, M.J. & Kelly, C.J. 2019. Seismic survey mitigation measures and protected species observer reports: synthesis report. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. Contract No.: M17PD00004. OCS Study BOEM 2019-012, 220 pp. Available from: https://espis.boem.gov/final%20reports/BOEM_2019-012.pdf [Accessed 1 September 2021].

Barton, C. 2012. JNCC MMO database manual. Available from JNCC on request.

Childerhouse, S., Douglas, L., Kennedy, J. & Burns, D. 2016. Analysis of marine observer data from New Zealand seismic surveys. BPM-15-DOC-Analysis of Marine Observer data from NZ seismic surveys-v1.4. 44pp. Available from: https://www.doc.govt.nz/globalassets/documents/conservation/native-animals/marine-mammals/seismic-code-of-conduct/mmo-prelim-data-analysis-report.pdf [Accessed 9 September 2021].

Cucknell, A.-C., Boisseau, O., Leaper, R., McLanaghan, R. & Moscrop, A. 2016. Harbour porpoise (*Phocoena phocoena*) presence, abundance and distribution over the Dogger Bank, North Sea, in winter. *Journal of the Marine Biological Association of the United Kingdom*, **97(7)**, 1,455–1,465. doi:10.1017/S0025315416000783

Hammond, P.S., Macleod, K., Berggren, P., Borchers, D.L., Burt, L., Cañadas, A., Desportes, G., Donovan, G.P., Gilles., A., Gillespie, D., Gordon, J., Hiby, L., Kuklik, I., Leaper, R., Lehnert, K., Leopold, M., Lovell, P., Øien, N., Paxton, C.G.M., Ridoux, V., Rogan, E., Samarra, F., Scheidat, M., Sequeira, M., Siebert, U., Skov, H., Swift, R., Tasker, M.L., Teilmann, J., Van Canneyt, O. & Vázquez, J.A. 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. *Biological Conservation*, **164**, 107–122. Available from: http://research-repository.st-andrews.ac.uk/handle/10023/3859 [Accessed 5 August 2021].

Heinemann, D. 1981. A range finder for pelagic bird censusing. *Journal of Wildlife Management*, **45**, 489–493.

JNCC. 2012. Marine mammal recording forms. JNCC, Peterborough. Available from: https://hub.jncc.gov.uk/assets/e2a46de5-43d4-43f0-b296-c62134397ce4 [Accessed 30 July 2021].

JNCC. 2017. JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys. JNCC, Peterborough. Available from: https://hub.jncc.gov.uk/assets/e2a46de5-43d4-43f0-b296-c62134397ce4 [Accessed 30 July 2021].

Northridge, S.P., Tasker, M.L., Webb, A. & Williams, J.M. 1995. Distribution and relative abundance of harbour porpoises (*Phocoena phocoena* L.), white-beaked dolphins (*Lagenorhynchus albirostris* Gray), and minke whales (*Balaenoptera acutorostrata* Lacepède) around the British Isles. *ICES Journal of Marine Science*, **52**, 55–66.

Nowacek, D.P., Bröker, K., Donovan, G., Gailey, G., Racca, R., Reeves, R.R, Vedenev, A.I., Weller, D.W. & Southall, B.L. 2013. Responsible practices for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. *Aquatic Mammals*, **39(4)**, 356–377. doi: 10.1578/AM.39.4.2013.356

Nowacek, D.P. & Southall, B.L. 2016. *Effective planning strategies for managing environmental risk associated with geophysical and other imaging surveys*. IUCN, Gland, Switzerland. 42pp. Available from: https://portals.iucn.org/library/sites/library/files/documents/2016-053.pdf [Accessed 3 September 2021].

Prawirasasra, M.S., Mustonen, M. & Klauson, A. 2019. Underwater monitoring of pinniped vocalizations in the Gulf of Riga. *Proceedings of Meetings on Acoustics*, **37**, 070015. doi: 10.1121/2.0001286

Siegel, S. & Castellan Jr, N.J. 1988. *Nonparametric statistics for the behavioral sciences.* McGraw-Hill Book Co., Singapore.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R. Jr., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A. & Tyack, P.L. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals*, **33(4)**, 411–414. doi: 10.1578/AM.33.4.2007.411

Stone, C.J. 1997. Cetacean observations during seismic surveys in 1996. *JNCC Report* No. 228. JNCC, Peterborough, ISSN 0963-8091. Available from: https://hub.jncc.gov.uk/assets/ba9bfa5e-cecd-410e-bfc8-de55e5880e18 [Accessed 10 September 2021].

Stone, C.J. 1998. Cetacean observations during seismic surveys in 1997. *JNCC Report* No. 278. JNCC, Peterborough, ISSN 0963-8091. Available from: https://hub.jncc.gov.uk/assets/6ee5617b-67a2-46f8-9603-a39c9c99a0fa [Accessed 2 August 2021].

Stone, C.J. 2000. Cetacean observations during seismic surveys in 1998. *JNCC Report* No. 301. JNCC, Peterborough, ISSN 0963-8091. Available from: https://hub.jncc.gov.uk/assets/964e1406-8f96-439a-8511-42364bb95258 [Accessed 2 August 2021].

Stone, C.J. 2001. Marine mammal observations during seismic surveys in 1999. *JNCC Report* No. 316. JNCC, Peterborough, ISSN 0963-8091. Available from: https://hub.jncc.gov.uk/assets/640fc705-0620-4c88-bf68-32cbeb5a33c0 [Accessed 2 August 2021].

Stone, C.J. 2003. Marine mammal observations during seismic surveys in 2000. *JNCC Report* No. 322. JNCC, Peterborough, ISSN 0963-8091. Available from: https://hub.jncc.gov.uk/assets/1c26d8bd-5408-44e7-a200-2d931b60ba91 [Accessed 2 August 2021].

Stone, C.J. 2006. Marine mammal observations during seismic surveys in 2001 and 2002. *JNCC Report* No. 359. JNCC, Peterborough, ISSN 0963-8091. Available from: https://hub.jncc.gov.uk/assets/29b0215a-9ca0-410f-8a87-e230013088ef [Accessed 2 August 2021].

Stone, C.J. 2015. Implementation of and considerations for revisions to the JNCC guidelines for seismic surveys. *JNCC Report* No. 463b. JNCC, Peterborough, ISSN 0963-8091. Available from: https://hub.jncc.gov.uk/assets/f7990481-7a99-414c-be04-b972da10c1b7 [Accessed 2 August 2021].

Teilmann, J. 2003. Influence of sea state on density estimates of harbour porpoise (*Phocoena phocoena*). *Journal of Cetacean Research and Management,* **5(1)**, 85–92.

Verfuss, U.K., Gillespie, D., Gordon, J., Marques, T.A., Miller, B., Plunkett, R., Theriault, J.A., Tollit, D.J., Zitterbart, D.P., Hubert, P. & Thomas, L. 2018. Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys. *Marine Pollution Bulletin*, **126**, 1–18. http://dx.doi.org/10.1016/j.marpolbul.2017.10.034

# Appendix 1 - Scientific names of species mentioned in the text

| | |
|---|---|
| Harbour seal | *Phoca vitulina* |
| Grey seal | *Halichoerus grypus* |
| 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* |
| Long-finned pilot whale | *Globicephala melas* |
| Killer whale | *Orcinus orca* |
| Risso's dolphin | *Grampus griseus* |
| Bottlenose dolphin | *Tursiops truncatus* |
| White-beaked dolphin | *Lagenorhynchus albirostris* |
| Atlantic white-sided dolphin | *Lagenorhynchus acutus* |
| Common dolphin | *Delphinus delphis* |
| Striped dolphin | *Stenella coeruleoalba* |
| Harbour porpoise | *Phocoena phocoena* |

# Appendix 2 - Glossary

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

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

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

**Areas of importance for marine mammals:** In the UK these include areas to the west of Shetland and areas designated as Marine Protected Areas (MPAs) with marine mammal species as qualifying features (e.g. the Moray Firth and Cardigan Bay for the bottlenose dolphin, the Southern North Sea and other areas for the harbour porpoise, plus areas for the harbour seal, grey seal, minke whale and Risso's dolphin).

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

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

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

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

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

**Effort:** Number of hours of visual or acoustic monitoring.

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

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

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

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

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

**Marine Noise Registry (MNR):** The registry records human activities in UK seas that produce loud, low to medium frequency (10 Hz–10 kHz) impulsive noise.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Shot point interval:** Interval between successive shots of the airguns (or other acoustic source), measured in metres along the ground (or sometimes in seconds).

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

**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, sparkers and chirp systems.

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

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

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

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

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

**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).