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Implementation of and considerations for revisions to the JNCC guidelines for seismic surveys

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

Summary

Data from 1,121 seismic surveys within the UK Continental Shelf (UKCS) between 1995 and 2010 were examined to assess compliance with the JNCC Guidelines for Minimising the Risk of Injury and Disturbance to Marine Mammals from Seismic Surveys (JNCC 2010 and earlier versions). Over 182,000 hours of monitoring (over 172,000 hours visual monitoring and over 9,000 hours acoustic monitoring) resulted in 8,452 sightings or acoustic detections of marine mammals, the most frequently encountered species (where identified) being the white-beaked dolphin. Airguns were firing for 39% of the time spent monitoring. Compliance with the JNCC guidelines was examined in detail between 2003 and 2010 (earlier years have been examined previously) and longer term trends in compliance were identified.

Standards of pre-shooting searches have remained stable over the years, with the majority being of adequate duration, although standards were lower on site surveys and vertical seismic profiling (VSP) operations. Standards of pre-shooting searches at night with passive acoustic monitoring (PAM) were lower than for visual searches in daytime.

Delays in firing due to the presence of marine mammals in the mitigation zone were required infrequently, although there was a slight increase over the five years to 2010. Delays were more likely to be required for the initial use of the airguns during a survey than for subsequent uses; the requirement for delays per airgun use was greatest on VSP operations, where airguns often only start firing once. The level of compliance with the requirement to delay firing was highly variable between years. Although there was some improvement, compliance with this aspect of the guidelines lagged behind that of pre-shooting searches and soft starts. On over a quarter of occasions when a delay was required firing commenced within 20 minutes of the last detection in the mitigation zone, while on one fifth of occasions the subsequent soft start was too short. In many cases there was apparently no attempt to delay firing, sometimes seemingly because the marine mammal observer (MMO), whether dedicated or not, was unaware that they were in a delay situation.

Standards of soft starts have improved over the years, largely due to the 2004 guideline revision allowing alternative methods of soft start for site surveys and VSP operations. This led to a marked reduction in the number of occasions when there was no soft start on these survey types. However, although the standard of soft starts on site surveys has improved it remains below that achieved on other survey types. VSP operations often had prolonged soft starts, while surveys with long line changes often had a prolonged period of firing at full power before the start of the survey line. Sometimes spare airguns were fired in addition to the airgun production array during the soft start, resulting in airgun volumes firing that exceeded the specified production volume.

On surveys with an airgun volume of 180 cubic inches (cu. in.) or less, in the majority of cases the decision to continue firing or to stop firing during line changes complied with the recommendations in the guidelines. For surveys with an airgun volume of 500 cu. in. or more, almost all occasions when firing continued during line changes were on ocean bottom cable (OBC) surveys. Typical line change durations on these surveys were such that the decision to continue firing or to stop firing was difficult and almost one third of line changes where firing continued exceeded the recommended maximum duration. On VSP operations there was confusion about what to do during gaps in acquisition, which could be prolonged; sometimes intermittent firing continued during these gaps, a procedure not included in the guidelines.

PAM was used in addition to visual monitoring on a minority of surveys, although its use has increased over time. It was used mostly in areas of importance for marine mammals or deep

water areas where deep-diving species may be found. Overall there were more occasions when firing commenced during hours of darkness or poor weather conditions without PAM than with PAM. Dolphins (often unidentified) were the most common marine mammals detected using PAM, followed by sperm whales and harbour porpoises. However, visual monitoring gave similar or higher detection rates than PAM for all species or species groups tested and in all cases was more effective than PAM at detecting marine mammals within the mitigation zone. Range estimation proved difficult with PAM. Other areas of concern with PAM included problems with deployment (e.g. recovery between survey lines, entanglement with seismic gear), problems of excessive background noise and software issues. Nevertheless, PAM resulted in a number of detections and was a viable monitoring method during periods when effective visual monitoring was not possible.

The use of dedicated MMOs on seismic surveys has increased over time. Compared to non-dedicated MMOs, dedicated MMOs were better at detecting marine mammals, had higher standards of compliance with the JNCC guidelines and the quality of data recorded was higher. Amongst dedicated MMOs, those with marine mammal experience prior to becoming an MMO had better detection skills and were better at recording behaviour.

Some trends in operations over time were identified. The number of seismic surveys reported per year, particularly site surveys and VSP operations, increased. There has been a general increase in surveys in the central North Sea, while in some other areas (west of Shetland, Rockall, Irish Sea and St George's Channel) surveys peaked in years coinciding with oil and gas licensing rounds in these areas. Seasonality was evident, particularly in exposed areas, on all types of seismic survey, although less so on VSP and OBC surveys.

To address the issues found, a number of items for consideration during any future revisions to the JNCC guidelines are suggested. These include: improved communication between seismic crews and MMOs/ PAM operators; additional guidance on the use of PAM; strengthening the existing best practice recommendations; consideration of restricting commencement of firing in weather conditions when an effective pre-shooting search cannot be made either visually or acoustically; clarifying the criteria for soft starts; revising criteria for line changes on surveys with large airgun arrays; restricting excess noise due to exceeding production volume; including new sections specific to VSP and OBC operations to address specific issues encountered on these operations; adequate staffing; encouraging operators to use appropriately experienced personnel; further clarification of existing mitigation measures; and further training elements for both MMOs and PAM operators.

Contents

Glossary

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

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

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

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

Areas of importance for marine mammals In the UK these include areas to the west of Shetland, the Moray Firth and Cardigan Bay.

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

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

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

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

Effort Number of hours of visual or acoustic monitoring.

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

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

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

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

Mini-airgun Airgun of volume less than or equal to 10 cu. in.

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

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

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

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

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

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

PAM Passive acoustic monitoring; listening for marine mammal vocalisations using hydrophones deployed in the water linked to specialist software.

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

Pre-shooting search Search for marine mammals prior to commencing firing of the airguns.

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

Shot point interval Interval between successive shots of the airgun(s), measured in metres along the ground (or sometimes in seconds).

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

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

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

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

UKCS UK continental shelf.

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

1 Introduction

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

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

Monitoring for the presence of marine mammals prior to commencing firing of the airguns is a key component of the JNCC guidelines. This is primarily achieved by visual means by MMOs who have undergone JNCC-recognised training (http://jncc.defra.gov.uk/page-4703). However, there is provision for passive acoustic monitoring (PAM) to be used at times when conditions are not conducive to effective visual monitoring (e.g. darkness, poor visibility and increased sea states). If marine mammals are detected (either visually or acoustically) within a defined mitigation zone, then the start of airgun firing must be delayed. When it is clear to start, the level of firing must increase gradually by using a soft start/ ramp up procedure to protect any undetected animals that may be close by. The primary role of the MMO or PAM operator is to provide advice to enable the crew to comply with the guidelines and hence mitigate potential negative impacts of seismic operations on marine mammals. This work involves collecting data on the seismic operations, the watches and any marine mammals observed. Marine mammal recording forms are available for this purpose (JNCC 2012) and all data from seismic surveys within the UKCS are returned to JNCC where, after appropriate quality checks, they are included in a database.

This report presents the results of an analysis of that database, including all data from 1995, when the guidelines were introduced, until the end of 2010. The aim of the analysis was to assess the level of compliance with the JNCC guidelines and in so doing suggest recommendations for best practice for consideration in any future revision to the guidelines.

The analysis focussed on:

- the pre-shooting search;
- delays in firing;
- the soft start;
- line change;
- passive acoustic monitoring;
- MMOs and PAM operators;
- trends in operations and compliance over time.

2 Methods

2.1 Marine mammal observations and effort

Marine mammal observations were undertaken from seismic surveys operating within the UKCS. Data from 1994 until 2010 were recorded, although only records since the introduction of the JNCC guidelines in 1995 were included when analysing compliance with the guidelines.

Visual watches for marine mammals were carried out during daylight hours. Observers ranged from biologists experienced in marine mammal surveys to non-scientific personnel who in many cases had undergone basic MMO training. In addition PAM was utilised on some surveys during night-time operations and sometimes also during the day. Since 1996, MMOs and PAM operators have completed standard marine mammal recording forms that require effort (number of hours of visual or acoustic monitoring) to be recorded as well as sightings. A number of versions of these forms have been issued over the years (latest version JNCC 2012), but all versions are compatible and were included in the database. Data on seismic operations were recorded on 'Operations' forms, introduced in 1998, that included times of pre-shooting searches, times of soft starts and any mitigating action required. Information on the watch/ acoustic monitoring period was recorded on 'Effort' forms, including the time, location, source activity and weather conditions. Information on marine mammal sightings/ acoustic detections was recorded on 'Sightings' forms, including species, number of animals, behaviour, closest distance of approach to the airguns and the airgun 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.

2.2 Airgun arrays

The observations encompassed a range of types of seismic survey with widely varying sizes of airgun array. The smallest airgun array volume was 6 cu. in., used on some site surveys, while the largest was 10,170 cu. in. (on a 2D survey). Very large volumes of airguns were rare; only nine surveys used volumes exceeding 5,500 cu. in. The frequency and source level of the airguns were often not recorded as this information was not requested on recording forms in earlier years. However, from available information arrays used on 2D, 3D, 4D and OBC surveys typically produce frequencies predominantly up to around 200Hz, with a peak-to-peak energy output from the source of around 130-140 bar metres, equating to a peak source level of around 256dB re. 1µPa @ 1m. Arrays used on site surveys and some vertical seismic profiling (VSP) operations typically produce frequencies predominantly up to around 250Hz, with a peak-to-peak energy output of around 10 bar metres, equating to a peak source level of around 235dB re. 1µPa @ 1m.

2.3 Data quality control

Only data of acceptable quality were entered into the database and were subject to analysis. Data checks were applied consistently following a standard list of over 60 checks (Barton 2012). Examples included: checking that source activity was accurately recorded during observation effort; that airgun array characteristics corresponded with information within the MMO report; that consecutive positions were credible given the time interval and speed of the vessel; and that species identity corresponded with the description and/ or photograph. Any errors found were corrected where possible. If data were accurate or minor inaccuracies were able to be corrected then the data were entered into the database. Data

with key information missing or errors that were not able to be corrected were discarded; approximately 15% of surveys had at least part of the associated data discarded, although this happened slightly less often (11%) on 2D, 3D, 4D and OBC surveys where dedicated MMOs were more often used. The recording forms have evolved over the years so it is not possible to make a meaningful comparison between years of the amount of data discarded.

After following the quality control process, data from a total of 1,121 surveys within the UKCS were available for analysis, spanning the period from 1995 to 2010.

2.4 Analysis and statistical tests

Only data from surveys within the UKCS since the guidelines were introduced in 1995 were analysed when assessing compliance with the JNCC guidelines. Where appropriate, data were grouped into broad geographic areas within the UKCS (Figure 2.1).

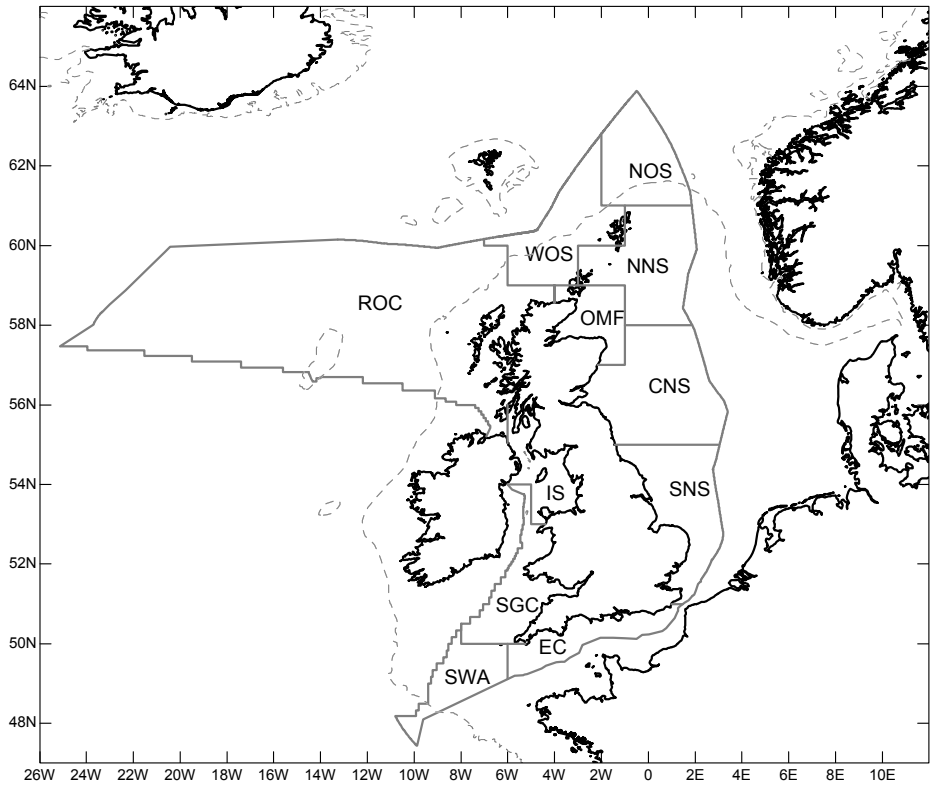

Figure 2.1. Geographic areas within the UKCS used in data analysis: CNS = Central North Sea; EC = English Channel; IS = Irish Sea; NNS = Northern North Sea; NOS = North of Shetland; OMF = Outer Moray Firth; ROC = Rockall; SGC = St George's Channel; SNS = Southern North Sea; SWA = South-west Approaches; 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 Licence v2.0, from the UK Hydrographic Office.

Compliance in the years to 2002 has been reported previously (Stone 1998, 2000, 2001, 2003, 2006), so a detailed analysis of compliance is only considered for 2003 onwards here although long term trends in compliance are considered over all years since 1995. Compliance was assessed in relation to the version of the guidelines that was current at the time. Any potential agreements within consent conditions to deviate from the standard JNCC guidelines were mostly not assessed, as any such agreed variations in the consent

were not usually recorded in the MMO reports. Compliance is mostly presented as the proportion of surveys meeting the best practice recommendations contained within the guidelines; where relevant, examples of good and poor practices (mostly from recent years) are described in more detail.

2.4.1 The pre-shooting search

Pre-shooting searches were required any time the airguns commenced firing after a period of silence; this included starting a mini-airgun at full power and soft starts for all other airgun types. The mean number of occasions per survey when firing commenced after a period of silence was determined for each survey type. All versions of the guidelines since 2004 have allowed firing to continue during short line changes (mostly found on site surveys) although the exact criteria have varied between versions. As this reduces the number of times when airguns commence firing from silence, the mean number of start-ups on site surveys was examined over time.

The JNCC guidelines require that a search for marine mammals is made for at least 30 minutes before firing commences, and since June 2009 for at least 60 minutes in waters deeper than 200m. The proportion of occasions when pre-shooting searches were adequate (meeting the required minimum duration and not terminating before firing commenced) was assessed for visual searches during daylight hours on all surveys and for acoustic searches at night on surveys where PAM was used. The proportion of adequate acoustic pre-shooting searches during daylight hours was assessed since June 2009 for surveys where PAM was used in areas of importance for marine mammals, as since then the guidelines have recommended that PAM is used to supplement visual observations in these areas.

2.4.2 Delays in firing

For surveys that were wholly within the UKCS (where all airgun use would have been subject to the JNCC guidelines) the number of occasions when a delay in firing was required due to the presence of marine mammals in the mitigation zone was compared to the total number of occasions when airguns were used each year. This could only be done for years from 1998 onwards, as data on seismic operations were not collated in earlier years. The number of delays required was considered in relation to the species detected, the method of detection (visual or acoustic), the survey type and the general location of the survey.

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 took at least 20 minutes to reach full power.

2.4.3 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. The soft start aims to protect any undetected marine mammals in close 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. For site surveys and vertical seismic profiling the guidelines, since 2004, have accepted alternative options for

performing the soft start, including increasing the pressure or increasing the firing frequency; the method of soft start used by these operations since 2004 was determined from reports.

The duration of soft starts was examined for all occasions when firing commenced after a period of silence and full power was reached prior to the survey line, 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 DECC and JNCC prior to the survey and highlighted within the MMO report.

For all surveys, the JNCC guidelines state that the gradual build up of power should be at least 20 minutes to allow adequate time for marine mammals to leave the area. The proportion of soft starts that lasted at least 20 minutes (from commencement until full power) was assessed, as was the proportion of occasions when there was no soft start. Since 2004 the guidelines have specified a maximum duration of 40 minutes from the beginning of the soft start until the start of the survey line; due to recording practices, data were only available since 2005 to assess the proportion of soft starts that exceeded this maximum duration. Since mid June 2009 the guidelines have required that once full power is reached the survey line should start immediately and that unnecessary firing at full power before the start of the line should be avoided. During analysis a few minutes were allowed for recording noise files, during which firing is paused briefly prior to the start of line; the proportion of occasions from July 2009 when the survey line commenced within five or 10 minutes of full power being reached was assessed.

MMO reports from 2009 and 2010 were examined for information on the progress of the soft start. 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. There were only 15 reports that detailed the progress of soft starts on 2D, 3D and 4D surveys.

Unplanned breaks in operations

The guidelines since 2009 have allowed firing to recommence without a full soft start if there is an unplanned break in firing of less than 10 minutes (providing a visual assessment of the mitigation zone has been made and no marine mammals detected). Prior to this the permitted break was just 5 minutes (since 2004, with informal guidance previously also allowing unplanned short breaks). The number of occasions when this provision was justifiably utilised was assessed, together with the mean and maximum duration of such short unplanned breaks in firing. Any longer breaks in firing would have required a soft start to recommence and would be included in the aforementioned assessment of compliance with the requirement for a soft start.

Test firing

The facility to distinguish between the airguns being fired for a survey line or for a test has been included on the 'Operations' form since June 2004, therefore test firing was examined from 2005 onwards. The mean number of tests (per year and per survey) and the proportion immediately preceding a survey line (with no break in firing 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 firing 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 firing until the start of the survey line. The mean duration of tests conducted separately from a line, where all firing was for the purpose of the test, was

measured from the start until the end of firing. 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 of 20 minutes was assessed.

2.4.4 Line change

Since June 2009 the guidelines have required that the airguns stop firing at the end of a survey line where the line change is expected to exceed a given duration. For airgun volumes of 500 cu. in. or more the threshold duration is 20 minutes, while for airgun volumes of 180 cu. in. or less the threshold duration is 40 minutes. To assess whether the specified durations are appropriate, data from 2009 and 2010 were examined to determine the median line change duration for the different survey types and what proportion of line changes were within or exceeded the specified time limits for different array volumes. Surveys were assigned to categories (180 cu. in. or less or 500 cu. in. or more) based on the reported airgun volume.

To assess compliance with the guidelines the duration of all line changes where firing continued was examined. Specific airgun array volumes were introduced as a criterion for determining procedures during line changes in mid June 2009, so only data from July 2009 until the end of 2010 were examined.

VSP operations

During VSP operations typically shots may cease for a short time periodically while the geophone is repositioned in the well. Although this is somewhat different from line changes on other types of survey, MMO reports were examined for any information on the duration of these gaps in firing and what procedures were implemented.

2.4.5 Passive acoustic monitoring

Use of PAM on surveys

The proportion of surveys using PAM during each year since the introduction of the JNCC guidelines was determined. Use of PAM according to survey type, location and season were also considered. MMO reports from recent years (2009 and 2010) were examined for information on whether PAM was used in daytime as well as at night, PAM deployment methods and the software used.

Use of PAM for operations commencing at night

The number of times when airguns commenced firing at night where PAM was used to search for marine mammals beforehand was compared to those commencing at night with no acoustic search beforehand. Only surveys since 2003 were analysed (full operations data were not included in the database prior to 2003). The number of start-ups at night with and without PAM was also considered in relation to location and survey type.

Surveys with PAM were used to test whether the presence of marine mammals at dusk could be used as an indicator of their presence during the night to help inform decisions on start-up if PAM was not available. All instances where visual observations ended at dusk and recommenced at dawn the next day with acoustic monitoring during the night in between

(not necessarily continuously) were examined for occasions when there were both acoustic detections at night and visual sightings in the two hours preceding nightfall.

Use of PAM for operations commencing in poor weather

The number of occasions when airguns commenced firing with and without PAM during suboptimal weather conditions (sea states recorded as 'choppy' or 'rough', or swell recorded as 'medium' or 'large', or visibility recorded as 'moderate' or 'poor') were compared in relation to survey type, for surveys since 2003. This was repeated for very poor weather conditions (sea state 'rough', swell 'large' or visibility 'poor'). This could only be done for soft starts where the weather conditions beforehand had been recorded on the 'Effort' form.

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 commonly detected. Sighting and acoustic detection rates per 100 hours of visual/ acoustic monitoring were compared on surveys where PAM was employed, using only sightings or acoustic detections with accompanying effort data. A number of variables can influence detection rates, for example weather conditions influence the ability of observers to detect marine mammals (e.g. Hammond *et al* 2013; Northridge *et al* 1995). Matched pairs were used to compare visual versus acoustic detection rates for periods during each day of each survey when sea state, swell and airgun activity were the same, thereby controlling for any influence of location, season, weather, survey type and noise. Visibility and sun glare were not accounted for as PAM operators did not record these. Therefore the visual watches used may have included periods of poor visibility or strong sun glare, leading to suboptimal conditions for visual monitoring. The process of identifying matched pairs eliminated many sightings/ acoustic detections that occurred during periods when only one form of monitoring was used, 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, all delphinids or all small odontocetes. These combined species groups comprised all identified and unidentified animals within that taxonomic grouping (Appendix 1,Table 8.1). The group of all small odontocetes included all the dolphin species (identified or unidentified) and the harbour porpoise.

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

To determine how effective PAM is for monitoring the presence of marine mammals within the 500m mitigation zone around the airguns, the above comparison of detection rates was repeated using only those detections within the mitigation zone.

Range estimation using PAM

An estimate of the range from the airguns of any marine mammals detected (either visually or acoustically) is needed to inform decisions regarding mitigation, in particular the need to delay firing. The proportion of acoustic detections with no estimate of range was compared to the proportion of visual detections with no estimate of range. For detections where range was estimated, as a guide to the accuracy of the range estimation the proportion of detections where range was not a multiple of 250m was used as an indicator of the minimum proportion where range was estimated to a greater level of accuracy than the nearest 250m. 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 airguns. 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'.

Delays in firing when using PAM

For acoustic detections range was often not recorded; when assessing the incidence of delays in firing for animals detected acoustically, if no range was given it was assumed that animals were outside the mitigation zone and a delay would not be required. The rate at which delays were required (number of delays per 1,000 hours monitoring) was compared for visual and acoustic monitoring, as was the implementation of these delays. The chi-squared test was used to compare the observed frequency of delays with each monitoring method with the expected frequency (allowing for differences in the time spent monitoring) had there been no difference between the two methods.

2.4.6 MMOs and PAM operators

Dedicated observers, non-dedicated observers and PAM operators

Requirements for MMOs are advised during the consent process for individual surveys. Since 2004 the JNCC guidelines have advised that two MMOs should be used north of 57^{o} latitude between 1st April and 1st October. The use of dedicated MMOs and PAM operators since the introduction of the JNCC guidelines in 1995 was assessed by calculating the mean number of personnel per survey in relation to year, month of commencement of the survey, location and type of survey.

Detection rates of dedicated and non-dedicated MMOs were compared, firstly at all times, then only during good weather conditions ('glassy' or 'slight' sea states, swell < 2m and visibility > 5km) when detection of marine mammals would have been easier. Only sightings with accompanying effort data were used. 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 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.

Benefits of relevant prior experience

The data were examined to see whether relevant prior experience gave dedicated MMOs any benefits in terms of performance. A sample of known observers were used, some with previous marine mammal experience before working as an MMO and the remainder without. Many had been dedicated MMOs for some years, but the only criteria considered was whether they had relevant experience prior to becoming an MMO.

Detection rates of MMOs with and without prior experience were compared, firstly at all times and then only during good weather conditions (as defined above). Only sightings with accompanying effort data were used. The ability to detect animals at distance was compared, using the mean closest distance of approach of animals, again at all times and then during good weather conditions only. The ability of observers to describe different behaviours (the mean number of behaviours used per observer and the mean number of behaviours per sighting) and the ability to record weather information were also compared.

2.4.7 Trends in operations and compliance over time

Trends in operations over time

The number of surveys reported in the UKCS was determined for each year since the introduction of the JNCC guidelines. Limited information on survey type exists in the database prior to 2003, but numbers of surveys of different types were determined for the years since then. Information on airgun array sizes, where known, was used to identify any trends in operational volume over time. Also considered were trends in the location of surveys.

Seasonal variation in operations

Data from all years were combined to determine the number of surveys per month in each geographical area and for each survey type. Surveys overlapping more than one month were assigned to the month of commencement.

Trends in compliance over time

Three key areas of compliance with the guidelines were compared over time. These were the number of visual pre-shooting searches during daylight hours that were at least 30 minutes long (or 60 minutes in deep waters since June 2009) and did not end prematurely, the number of soft starts that were at least 20 minutes long and the proportion of delays that were correctly implemented (delay of at least 20 minutes plus subsequent soft start of at least 20 minutes). Compliance was compared as far back as records would allow; pre-shooting searches and soft starts were compared for all years since 1998 (when operations data were first recorded), while delays were compared since the introduction of the guidelines in 1995.

Occurrence of poor practices (e.g. continuing to fire airguns during long line changes) in 2009 and 2010 were considered in relation to the frequency with which the client or seismic contractor operated surveys within the UKCS. For clients or contractors operating a given number of surveys within the UKCS, the mean percentage of surveys where poor practices were found was assessed.

3 Results

3.1 Overview of survey effort and species encountered

A total of 182,426 hours 35 minutes were recorded as monitoring for marine mammals during seismic surveys within the UKCS between 1996 and 2010 (effort was not recorded prior to 1996), comprising 172,819 hours visual monitoring and 9,607 hours 35 minutes acoustic monitoring. The airguns were firing for 39% of the total time spent monitoring.

There were 8,452 sightings or acoustic detections of marine mammals, comprising 112,002 individuals (Appendix 1,Table 8.2). The most frequently encountered species of marine mammal identified was the white-beaked dolphin (an encounter being one or more animals occurring together). Minke whales, Atlantic white-sided dolphins, harbour porpoises, sperm whales, long-finned pilot whales, fin whales and killer whales were also regularly seen. Mixed species associations occurred on 148 occasions, with long-finned pilot whales and Atlantic white-sided dolphins being the most common combination. Full details of survey effort and species occurrence are reported elsewhere (Stone 2015).

3.2 The pre-shooting search

The number of times when firing commenced after a period of silence on each survey varied considerably. The mean number of start-ups per survey was highest for 3D and 4D surveys and lowest for site surveys and VSP, which are both usually of short duration (Figure 3.1). The mean number of start-ups on site surveys decreased from 2004 onwards (Figure 3.1).

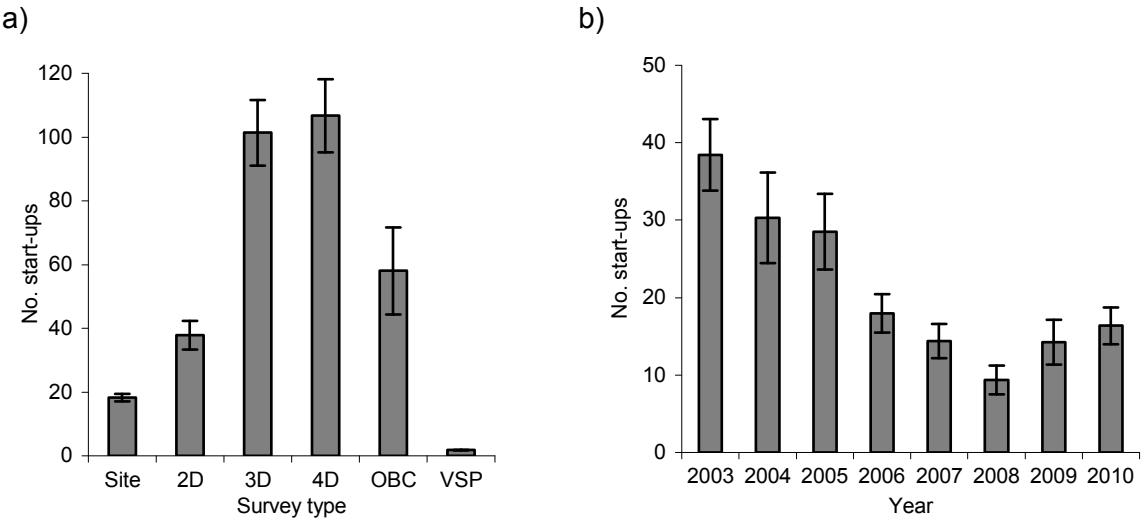

Figure 3.1. Mean number (and standard error) of start-ups per survey: a) all surveys, 1995-2010; b) site surveys, 2003-2010.

On 2D, 3D, 4D and OBC surveys the majority of visual pre-shooting searches prior to commencing firing during daylight were of adequate duration (Table 3.1). For site surveys and VSP operations standards of pre-shooting searches were lower. Although a mini-airgun was not often used (n=185), only 58% of visual pre-shooting searches prior to its use during daylight hours were of adequate duration, with no pre-shooting search on 38% of occasions.

Table 3.1. Percentage (and sample size) of adequate duration visual pre-shooting searches during daylight within the UKCS.

Year	Site		VSP		2D		3D		4D		OBC		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)**
Total	**72.3**	**(4,083)**	**74.0**	**(123)**	**90.1**	**(1,071)**	**92.8**	**(3,833)**	**93.0**	**(2,738)**	**92.3**	**(627)**	**85.7**	**(12,475)**

Standards of acoustic pre-shooting searches at night on surveys where PAM was used were generally lower than those of visual pre-shooting searches during daylight (Table 3.2). Since July 2009, where PAM was used in areas of importance for marine mammals there were relatively few adequate acoustic pre-shooting searches during daylight (Table 3.3); on many occasions (51%) there was no acoustic pre-shooting search. The apparently very low use of PAM during daylight in the latter half of 2009 may have been partly an artefact due to a number of MMOs and PAM operators continuing to use older recording forms at this time.

Table 3.2. Percentage (and sample size) of adequate duration acoustic pre-shooting searches at night within the UKCS (only surveys where PAM was used).

Year	Site		VSP		2D		3D		4D		OBC		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)**
Total	**69.5**	**(200)**	**100.0**	**(4)**	**51.2**	**(125)**	**71.6**	**(447)**	**69.9**	**(302)**	**48.6**	**(35)**	**67.8**	**(1,113)**

Table 3.3. Percentage (and sample size) of adequate duration acoustic pre-shooting searches in daylight in areas of importance for marine mammals within the UKCS (only surveys where PAM was used, July 2009 – December 2010).

Year	Site		VSP		2D		3D		4D		OBC		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)**
Total	**47.9**	**(144)**	**33.3**	**(3)**	**0.0**	**(19)**	**1.7**	**(119)**	**89.7**	**(185)**	**22.5**	**(138)**	**44.2**	**(608)**

Most inadequate pre-shooting searches did not start far enough in advance of firing commencing; overall 89% of inadequate daylight visual searches and 95% of inadequate night-time PAM searches started too late. A smaller proportion (12% of inadequate daylight visual searches and 6% of inadequate night-time PAM searches) finished too early, terminating before firing commenced. For both visual observations and night-time PAM, these percentages included 1% of inadequate pre-shooting searches that both started too late and ended prematurely.

Pre-shooting searches were generally conducted with no significant problems, but occasional issues with the pre-shooting search in recent years included:

- very short searches due to late notification by the crew to the MMO/ PAM operator;
- no search being conducted prior to use of a mini-airgun;

- MMOs not conducting a visual search during increased sea states (even though firing was still planned to commence);
- no search due to an inadequate level of staffing (particularly during the summer months when daylight hours were prolonged throughout the UKCS);
- and lack of availability of UHF radios for communication during the pre-shooting search, with insufficient numbers of radios on the vessels to allow for use by additional third party crew such as MMOs and PAM operators.

3.3 Delays in firing

There were 165 occasions within the UKCS when firing was required to be delayed due to the presence of marine mammals within the mitigation zone, since the introduction of the guidelines in 1995 until the end of 2010. In comparison to the usage of the airguns the number of delays required was low (Table 3.4), with on average one delay required for every 222 uses of the airguns over the period since 1998. However, in the last five years (2006-2010) delays were required for an average of one in every 161 uses of the airguns, indicating a recent increase in the incidence of delay situations. This was apparently partly due to the increased use of PAM in recent years, which led to increased monitoring prior to starting firing (particularly at night) and more animals being detected than would be by visual means alone. Where the reason for firing was recorded 80% of delays were required prior to firing a line (without testing beforehand), 14% were required prior to testing, and 5% were required prior to testing that led straight into a survey line.

Table 3.4. Number and percentage of occasions when a delay in firing 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
2010	19	2,712	0.7
Total	**154**	**33,386**	**0.5**

Delays were required more often due to the presence of dolphins in the mitigation zone than other species (Table 3.5). White-beaked dolphins and Atlantic white-sided dolphins were the species that most commonly caused delays to be required, followed by unidentified dolphins and harbour porpoises. Fewer delays were required due to the presence of minke whales, long-finned pilot whales, killer whales, large baleen whales, sperm whales or seals.

Table 3.5. Number of occasions when a delay in firing was required within the UKCS due to marine mammals in the mitigation zone by species/ species group.

Species	Number of delays
Unidentified seals	4
Harbour seal	1
Grey seal	3
Unidentified cetaceans	5
Unidentified large whales	3
Unidentified large baleen whales	3
Humpback whale	1
Fin whale	1
Sei whale	1
Sperm whale	2
Unidentified medium whale	2
Minke whale	9
Long-finned pilot whale	6
Killer whale	5
Unidentified dolphins	22
Risso's dolphin	1
Bottlenose dolphin	4
White-beaked dolphin	41
Atlantic white-sided dolphin	32
Short-beaked common dolphin	3
Harbour porpoise	17

Most delays were required due to animals being detected visually (Figure 3.2), reflecting the prevalence of visual monitoring, although there was no significant difference in the rate at which delays were required relative to the monitoring method (section 3.6.6). The proportion of occasions when a delay was required was greatest on VSP operations (Table 3.6). Delays were more likely at the beginning of a survey; since 2003 delays were required for one of every 131 survey lines or airgun tests that were the first shots of the survey, but for only one of every 185 subsequent lines or tests. The requirement to delay per airgun use was highest in St George's Channel, although infrequent surveying in this area meant the sample size was low (Table 3.7). Of areas surveyed more frequently, delays were required most often to the west of Shetland and least often in the southern North Sea. There were no trends in the requirement to delay over time in each area.

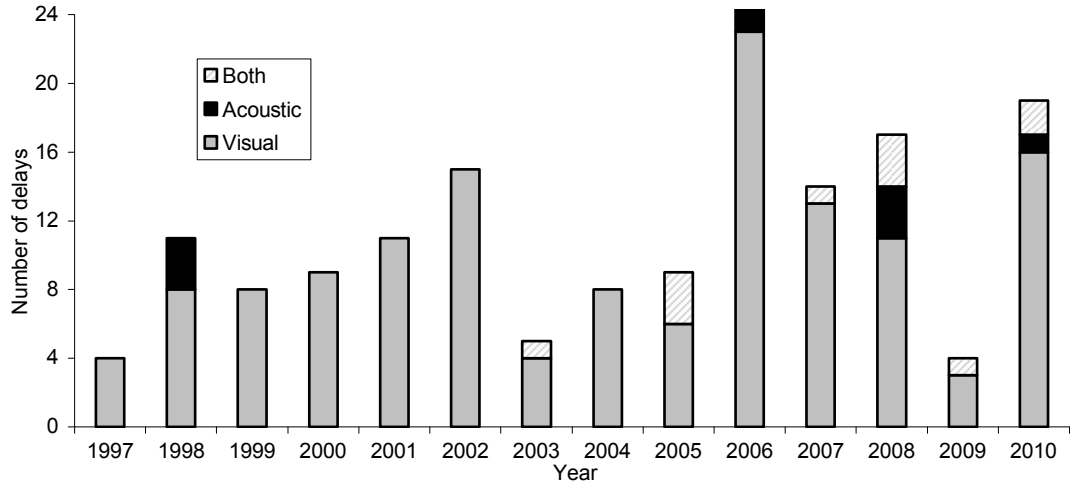

Figure 3.2. The number of delays in firing required within the UKCS due to marine mammals in the mitigation zone according to the method of detection (visual, acoustic or both).

Table 3.6. Number and percentage of occasions when a delay in firing was required on different types of survey (on surveys wholly within the UKCS).

Type of survey	Number of delays	Number of times airguns commenced firing	% occasions when a delay was required prior to firing
Site	43	10,351	0.4%
VSP	2	171	1.2%
Unspecified type with large airgun arrays	38	9,759	0.4%
2D	16	1,711	0.9%
3D	22	5,883	0.4%
4D	27	4,001	0.7%
OBC	6	873	0.7%

Table 3.7. Number and percentage of occasions when a delay in firing was required on surveys in different areas of the UKCS (on surveys wholly within the UKCS).

Area	Number of delays	Number of times airguns commenced firing	% occasions when a delay was required prior to firing
Northern North Sea	22	6,930	0.3%
Central North Sea	38	10,144	0.4%
Outer Moray Firth	15	2,466	0.6%
Southern North Sea	4	4,486	0.1%
West of Shetland	41	3,803	1.1%
North of Shetland	16	2,667	0.6%
Rockall	5	764	0.7%
Irish Sea	2	696	0.3%
St George's Channel	2	54	3.7%

Correct procedures were not always followed when a delay in firing was required (Table 3.8). The most common incorrect practice, found in over a quarter of delay situations, was that firing commenced within 20 minutes of the animals last being detected in the mitigation zone (on average 9.5 minutes after the animals were last seen in the mitigation zone). Often the soft start subsequent to the delay was too short and occasionally both the duration of the delay and the subsequent soft start were too short.

Table 3.8. Number and percentage of occasions when correct/ incorrect procedures were followed when a delay in firing 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		< 20 mins before firing commenced		No attempt to delay firing		Subsequent soft start too short		Both delay and subsequent soft start too short	
1997*	>=1	(>=25.0%)	?		0	(0.0%)	?		?	
1998	2	(18.2%)	4	(36.4%)	2	(18.2%)	7	(63.6%)	2	(18.2%)
1999	1	(12.5%)	4	(50.0%)	3	(37.5%)	5	(62.5%)	2	(25.0%)
2000	7	(77.8%)	1	(11.1%)	1	(11.1%)	1	(11.1%)	0	(0.0%)
2001	4	(36.4%)	5	(45.5%)	3	(27.3%)	3	(27.3%)	1	(9.1%)
2002	11	(73.3%)	2	(13.3%)	2	(13.3%)	3	(20.0%)	1	(6.7%)
2003	3	(60.0%)	1	(20.0%)	1	(20.0%)	2	(40.0%)	1	(20.0%)
2004	7	(87.5%)	1	(12.5%)	1	(12.5%)	1	(12.5%)	1	(12.5%)
2005	2	(22.2%)	5	(55.6%)	4	(44.4%)	3	(33.3%)	1	(11.1%)
2006	17	(54.8%)	12	(38.7%)	8	(25.8%)	4	(12.9%)	2	(6.5%)
2007	9	(64.3%)	4	(28.6%)	3	(21.4%)	1	(7.1%)	0	(0.0%)
2008	15	(88.2%)	1	(5.9%)	0	(0.0%)	2	(11.8%)	1	(5.9%)
2009	3	(75.0%)	0	(0.0%)	0	(0.0%)	1	(25.0%)	0	(0.0%)
2010	15	(78.9%)	4	(21.1%)	2	(10.5%)	0	(0.0%)	0	(0.0%)
Total	**97**	**(58.8%)**	**44**	**(26.7%)**	**30**	**(18.2%)**	**33**	**(20.0%)**	**12**	**(7.3%)**

* 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 many of the occasions when firing commenced within 20 minutes of marine mammals being detected in the mitigation zone, there was no apparent attempt to delay firing (Table 3.8). Although the requirement to delay firing should not be circumvented, there were various circumstances apparent from the MMO reports that may explain why there was no delay on some of these occasions. These can be grouped into various categories:

- human error (the MMO being told the wrong time when the soft start was due to begin; the MMO thinking the airguns were already firing);
- inadequate staffing (a single MMO covering long daylight hours and not being on watch at the required time);
- the MMO perhaps believing that it was acceptable not to delay (animals at the very edge of the mitigation zone; visual confirmation that animals had moved well outside the mitigation zone);
- lack of awareness of the requirements of the guidelines (animals seen by someone other than the MMO; on some rare occasions, the MMO being untrained);
- and, in a small number of earlier cases, compliance with the guidelines not being a licence condition (initially compliance was included as a licence condition but only for blocks licensed after the development of the guidelines).

However, on 11 of the 30 occasions when there was no attempt to delay there was no apparent reason and it appeared that the MMO was simply unaware that firing was imminent at the time when the animals were detected. These occasions were not restricted to any particular survey type and occurred with both dedicated and non-dedicated MMOs; however, in general dedicated MMOs had a higher rate of delays being implemented correctly (section 3.7.1). There were no reports of crews refusing to co-operate if the MMO advised a delay, although the delays that were implemented were not always long enough. In one instance the MMO noted that there was a 22 minute delay but the actual times recorded showed that the delay was only 18 minutes long.

In two cases MMOs, aware that a delay was required, decided that a delay was not necessary. Firing commenced 13 minutes after a minke whale was first detected in the mitigation zone (the time it left the zone was not recorded) and nine minutes after a grey seal was last seen in the mitigation zone. In both cases the dedicated MMOs cited the movement of the animal away from the vessel as a reason for not delaying, even though the seal had not been confirmed to have left the mitigation zone and the whale was still close to the zone. The solitary nature of seals offshore and their tendency not to follow ships were also given as justifications for not delaying for the seal, while in the case of the whale constraints of time-sharing were noted. Conversely, on one survey operations were delayed for over five hours until daylight on the advice of the dedicated MMO following a sighting of a large, dispersed group of white-beaked dolphins in the mitigation zone for over an hour late one evening.

3.4 The soft start

Increasing the frequency of firing was a popular method of performing the soft start on site surveys since 2004, while on VSP operations this method was never used with the number of airguns or pressure being increased instead (Figure 3.3).

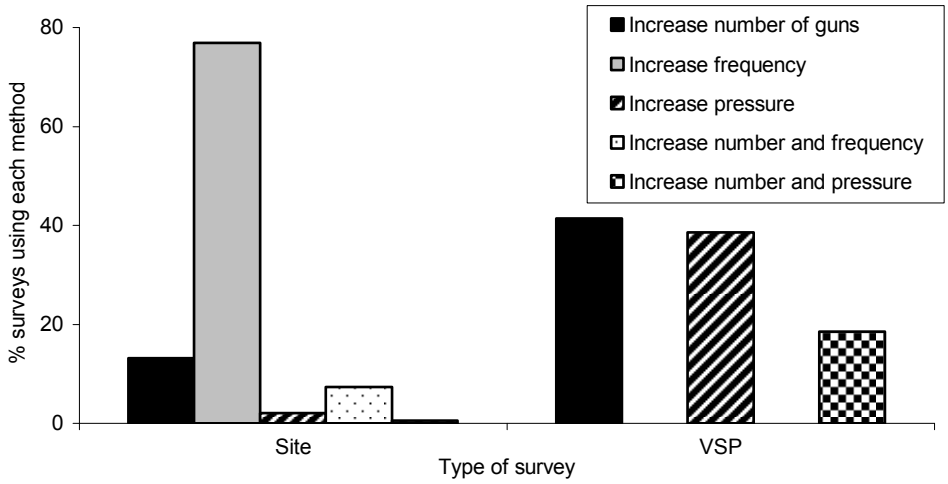

Figure 3.3. Method of soft start used on site surveys and VSP since 2004.

Soft starts were most often of adequate duration on 3D and OBC surveys (Table 3.9), whilst site surveys had the lowest proportion of adequate soft starts (Table 3.9) and the lowest mean duration (Table 3.10). Duration of soft starts on site surveys steadily improved for several years from 2004 onwards, before reaching a plateau still somewhat below the standard achieved on other types of survey (Table 3.9).

Table 3.9. Percentage (and sample size) of soft starts within the UKCS lasting at least 20 minutes from the commencement of the soft start until full power, by year and type of survey (excluding test firing and the use of a mini-airgun).

Year	Site		VSP		2D		3D		4D		OBC		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)**
Total	**53.8**	**(5,690)**	**87.0**	**(115)**	**88.3**	**(1,476)**	**95.3**	**(5,340)**	**87.2**	**(3.517)**	**95.9**	**(664)**	**78.9(16,802)**

Table 3.10. Mean duration from the commencement of the soft start until full power and until the start of line, within the UKCS, by type of survey (excluding test firing and the use of a mini-airgun).

	Site	VSP	2D	3D	4D	OBC
Soft start - full power (mins)	15	34	23	22	22	22
Soft start - start of line (mins)	25	58	31	32	37	31

Until 2004 it was common for there to be no soft start on site surveys, with the airguns commencing firing at full power. After 2004 there was a dramatic reduction in the number of occasions when there was no soft start on site surveys (Table 3.11) (slight increases in 2007 and 2009 were due mostly to one site survey in each of these years where compliance was poor). The same was true for VSP operations.

Table 3.11. Percentage (and sample size) of occasions when there was no soft start within the UKCS by year and type of survey (excluding test firing and the use of a mini-airgun).

Year	Site		VSP		2D		3D		4D		OBC		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)**
Total	**21.0**	**(5,690)**	**5.2**	**(115)**	**0.1**	**(1,476)**	**1.0**	**(5,340)**	**0.2**	**(3,517)**	**0.3**	**(664)**	**7.6(16,802)**

Soft starts on VSP operations often exceeded 40 minutes from the beginning of the soft start until the start of line, while site surveys performed best in this respect (Table 3.12). The mean duration from the beginning of the soft start until the start of line was within 40 minutes for all surveys except VSP (Table 3.10).

Table 3.12. Percentage (and sample size) of occasions when the time from the beginning of the soft start until the start of line exceeded 40 minutes within the UKCS by year and type of survey (excluding test firing and the use of a mini-airgun).

Year	Site		VSP		2D		3D		4D		OBC		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)**
Total	**4.2**	**(3,012)**	**33.8**	**(42)**	**12.6**	**(713)**	**8.0**	**(1,910)**	**20.1**	**(1,110)**	**11.8**	**(415)**	**9.1 (7,202)**

The number of occasions when the survey line started soon after full power was reached was relatively low (Table 3.13), especially for those surveys where line changes are long (2D, 3D and 4D surveys). Site surveys were better than other types of surveys at commencing the survey line soon after reaching full power. On 10 occasions between July 2009 and December 2010 firing continued at full power for more than an hour prior to the start of line; these occasions happened on all types of survey except OBC surveys.

Table 3.13. Duration from full power being reached until the start of the survey line, from July 2009 to December 2010 within the UKCS, by type of survey (excluding test firing and occasions when the airguns continued firing between lines during short line changes).

	Site	VSP	2D	3D	4D	OBC	Total
% ≤ 5 mins	80.8	63.2	9.2	14.9	5.0	39.9	**38.6**
% ≤ 10 mins	92.3	73.7	21.1	52.5	21.7	73.5	**62.0**
Mean	4	20	20	11	14	8	
Maximum	81	162	247	169	161	44	
n	999	19	76	944	544	298	**2,880**

Although the majority of soft starts in recent years were adequate, there were some examples of poor practices, which included:

- not being able to conduct a soft start due to shot point controls being linked to fixed points during the lines and therefore the airguns not being able to be fired prior to the line to conduct a soft start, but no alternative arrangements being discussed with DECC or JNCC;

- no soft start due to late notification of operations amongst the seismic crew;
- alternative methods of achieving the soft start (i.e. increasing the pressure or firing frequency) being used for surveys with larger airgun volumes than is intended in the guidelines;
- shortening the soft start due to time-sharing;
- and including additional airguns during the soft start such that the maximum volume achieved greatly exceeded the specified production volume.

Of 15 MMO reports that detailed the progress of soft starts on 2D, 3D and 4D surveys in 2009 and 2010, 10 recorded that spare airguns were used in the soft start in addition to the other airguns, resulting in a maximum volume being reached that exceeded the specified production volume (Table 3.14). The mean percentage increase in airgun volume above the production volume during soft starts on 2D, 3D and 4D surveys combined was 16%. The maximum was 77%, this being on one 3D survey where the volume firing during the soft start increased to 5,120 cu. in. even though the production volume was only 2,900 cu. in. Site surveys, OBC surveys and VSP operations were not recorded as exceeding production volume during the soft start process.

Table 3.14. Increase in volume of airguns firing during the soft start above production volume (2009-2010 data only).

Type of survey	% surveys where soft start volume exceeded production volume	Mean % increase	Maximum % increase	Sample size
Site	0.0	0.0	0.0	95
VSP	0.0	0.0	0.0	8
2D	83.3	10.7	13.4	6
3D	80.0	25.2	76.6	5
4D	25.0	12.2	48.9	4
OBC	0.0	0.0	0.0	3

3.4.1 Unplanned breaks in operations

Available data since 2003 indicated that there were few occasions when firing recommenced without a full soft start after a short unplanned break in firing (Table 3.15). On most of these occasions firing resumed at full power after the short break, but in 2005 and 2009 a short soft start was conducted after these short breaks. An increase in short breaks in firing with the airguns resuming at full power in 2010 was largely due to very short line changes on an OBC survey, which would not qualify as being unplanned.

Table 3.15. Short breaks in firing where the airguns resumed without a full soft start.

Year	Number of short breaks	Mean duration (mins)	Maximum duration (mins)
2003	1	5	5
2004	0	-	-
2005	4	2	4
2006	1	< 1	< 1
2007	1	4	4
2008	2	2	3
2009	2	4	4
2010	86	5	10

3.4.2 Test firing

Site surveys and VSP operations had fewer tests per survey than other survey types (Table 3.16), which might reflect their shorter duration. However, the number of site surveys meant that, in spite of having few tests per survey, the total number of tests per year during site surveys was amongst the highest. Some tests were carried out separately from survey lines, with the airguns ceasing to fire once the test was complete, while others were carried out immediately prior to a survey line, with firing continuing into the line. Surveys with long line changes (2D, 3D and 4D surveys) had fewer tests that continued into the line, perhaps reflecting the increased scope for testing separately from the line when line changes were longer. Tests on site surveys and VSP operations were more likely to reach full power; this would be expected if the test was followed by a line, but may also reflect the small number of airguns (typically three, four or six) used in arrays on site surveys and VSP operations. With a low number of airguns it would be more likely that all would be fired together during a test than where arrays contain several tens of airguns (as is typical of 2D, 3D, 4D and OBC surveys) and there is more flexibility for firing only part of the array at once.

Where tests were followed immediately by a survey line, on some occasions a 'normal' duration soft start was performed and then the test continued at full power until the start of line, while on other occasions the test was apparently included within a prolonged build up of power. The duration of tests was shortest on site surveys, whether followed immediately by a line or not (Table 3.16), possibly reflecting the short duration of line changes in which to perform a test. Across all types of survey an average of 158 hours 49 minutes was spent testing the airguns each year (approximately 2% of the average time recorded as firing each year), representing a small but notable contribution to noise input to the marine environment.

Where the level of firing during tests reached full power, most soft starts were at least 20 minutes duration. For OBC surveys the standard of soft starts during testing was lower, but the sample size of tests reaching full power was small for this survey type.

Table 3.16. Test firing of airguns from 2005 to 2010 within the UKCS, by type of survey.

	Site	VSP	2D	3D	4D	OBC
Mean number of tests per year	67	7	25	69	49	6
Mean number of tests per survey	2	2	6	12	18	5
% tests followed immediately by a survey line	30.9	38.1	7.5	4.6	6.8	13.9
Mean duration per test (minutes) when not followed immediately by a survey line	29	98	46	35	52	78
Mean duration per test (minutes) when followed immediately by a survey line	34	55	61	48	92	41
% tests that reached full power	78.8	95.2	42.9	18.9	40.4	58.3
Mean duration soft start where full power reached (mins)	24	39	23	26	31	21
% soft starts at least 20 mins where full power reached	86.9	97.5	85.2	95.9	92.5	77.8
Sample size of tests where full power reached	237	40	61	73	106	9

3.5 Line change

There were fewer line changes on site and 2D surveys than on 3D and 4D surveys, with OBC surveys having the greatest number of recorded line changes (Table 3.17). Surveys where multiple towed streamers necessitate slow, gradual turns (3D and 4D surveys) or where lines were widely spaced (2D surveys) had line changes of a long duration, while site surveys and OBC surveys had much shorter line changes (Table 3.17).

Table 3.17. Mean number of line changes per survey (and sample size = number of surveys) and median duration of line changes (and sample size = number of line changes; durations were assessed using 2009 and 2010 data only).

Type of survey	Mean number of line changes		Median duration of line change (minutes)	
Site	43	(364)	31	(5,693)
2D	41	(57)	277	(162)
3D	94	(68)	196	(1,025)
4D	99	(37)	209	(456)
OBC	226	(15)	22	(2,864)

In 2009 and 2010, for surveys with airguns volumes of 180 cu. in. or less, the majority of lines changes were of up to 40 minutes duration (Table 3.18Table 3.18). For all surveys with airgun volumes of 500 cu. in. or more, the majority of line changes were longer than 20 minutes (Table 3.18). However, a clear distinction existed between different types of surveys with large airgun arrays. On OBC surveys the source vessel does not tow streamers so it can turn relatively quickly, making line changes much shorter than on other surveys with large airgun arrays. In 2009 and 2010, for all other surveys with large airgun arrays very few line changes were completed within 20 minutes, while for OBC surveys there was a more even split between line changes within or exceeding 20 minutes (Table 3.18). However, line changes on OBC surveys did not greatly exceed 20 minutes, with most completed within 30 minutes.

Table 3.18. Percentage of line changes within a given duration in relation to array volume (2009 and 2010 data only).

Volume of airguns	Duration of line change	% line changes
≤180 cu. in.	≤ 40 mins	76.7
	> 40 mins	23.3
≥ 500 cu. in.	≤ 20 mins	27.5
	> 20 mins	72.5
≥ 500 cu. in. (excluding OBC)	≤ 20 mins	2.8
	> 20 mins	97.2
OBC	≤ 20 mins	41.9
	> 20 mins	58.1
	≤ 30 mins	84.2

For smaller airgun arrays (up to 180 cu. in.) there were many occasions when firing continued during line changes, all on site surveys; some continued firing the full array while others continued at a reduced volume. On most occasions when firing continued the line changes were completed within 40 minutes (Table 3.19). Most that exceeded this did so only by a few minutes, with only 2% of line changes where firing continued being over 50 minutes duration. Occasionally firing continued during prolonged line changes, including one in 2009 that was over 4 hours in duration. Where reasons were given for exceeding 40 minutes, these were usually due to a decrease in speed caused by tides or currents, or human error when calculating expected line change times.

Table 3.19. Number of line changes within a given duration where firing continued during the turn in relation to array volume (data from July 2009 – December 2010 within the UKCS only).

Volume of airguns	Duration of line change	Number (and %) line changes where firing continued	
≤180 cu. in.	≤ 40 mins	3,155	(91.5)
	41-50 mins	212	(6.1)
	> 50 mins	82	(2.4)
≥ 500 cu. in. (excluding those where there was an agreement to allow firing to continue during line changes up to 25 minutes)	≤ 20 mins	177	(68.3)
	21-30 mins	64	(24.7)
	> 30 mins	18	(6.9)
≥ 500 cu. in. (where there was an agreement to allow firing to continue during line changes up to 25 minutes)	≤ 25 mins	930	(77.2)
	26-30 mins	234	(19.4)
	> 30 mins	40	(3.3)

Most (99%) occasions where firing continued between lines on surveys with airgun volumes of 500 cu. in. or more during the latter half of 2009 and 2010 were on OBC surveys. Firing often continued (usually at reduced power) if the line change was expected to be less than 20 minutes, either with or without consultation with DECC or JNCC. Where there was consultation this was sometimes extended to allow firing to continue for line changes of up to 25 minutes duration. Excluding those surveys where an extension was agreed, where firing continued during line changes on surveys with airgun volumes of 500 cu. in. or more almost one third of those line changes exceeded 20 minutes; however, only 7% were longer than 30 minutes (Table 3.19). On the two OBC surveys where it was agreed that firing could continue for line changes of up to 25 minutes duration, almost one quarter of line changes when firing continued exceeded this duration, perhaps indicating the difficulty even with an increased threshold; only 3% had line changes exceeding 30 minutes (Table 3.19).

On rare occasions on surveys with large airgun arrays a ‘mitigation gun’ (a single airgun of small volume) was fired during long line changes. This practice is common in some other jurisdictions (e.g. the Gulf of Mexico). On some other occasions MMOs reported that crews had planned to use a ‘mitigation gun’, but the MMOs had advised against it.

Only three surveys (two site surveys and one VSP) during the latter half of 2009 and 2010 had airgun volumes between 180 cu. in. and 500 cu. in. In all three cases firing stopped between lines. Data on line change durations were only available for one of the site surveys; of 17 line changes only two were under 40 minutes and none were under 20 minutes.

3.5.1 VSP operations

Data from 114 VSP operations were included in the database. It was unclear from the data what duration the gaps in VSP operations were and whether the airguns were stopped during these gaps or continued firing. Some MMO reports in 2004 and 2006 referred to periods of silence within the range of 5-10 minutes, but these silent periods were not recorded on the ‘Operations’ form. Several reports in 2009 and 2010 referred to continuing to fire shots at 5-10 minute intervals during gaps in acquisition that were mostly of unspecified duration; again these gaps in acquisition were not recorded properly on the ‘Operations’ form, although there was one occasion when it was reported that a shot was fired every nine minutes for over 1½ hours. There was clearly confusion on VSP operations about whether to continue to fire during gaps in acquisition and if so, what interval to fire at and how long this could continue without the airguns having to be stopped and another soft start performed on recommencing. Most operators decided on their course of action without

consultation with DECC or JNCC. Untrained observers were very occasionally used on VSP operations.

3.6 Passive acoustic monitoring

3.6.1 Use of PAM on surveys

A total of 76 surveys have used PAM since the guidelines were introduced in 1995; its use steadily increased, reaching 16% of surveys in 2010 (Figure 3.4). Trials were conducted on one survey each year between 1996 and 1998 and then PAM was not used again until 2002. Of the 76 surveys employing PAM, 52 had large volumes of airguns (e.g. 2D, 3D, 4D, OBC surveys). The use of PAM on surveys with smaller airgun volumes has mainly been in recent years (Figure 3.5); all except two site surveys with PAM have been from 2008 onwards and PAM has only been used for VSP operations since 2009. In addition, PAM was used on one baseline environmental survey with no airguns in 2002 and on the sole wide azimuth survey (with a large volume of airguns) that took place in 2010.

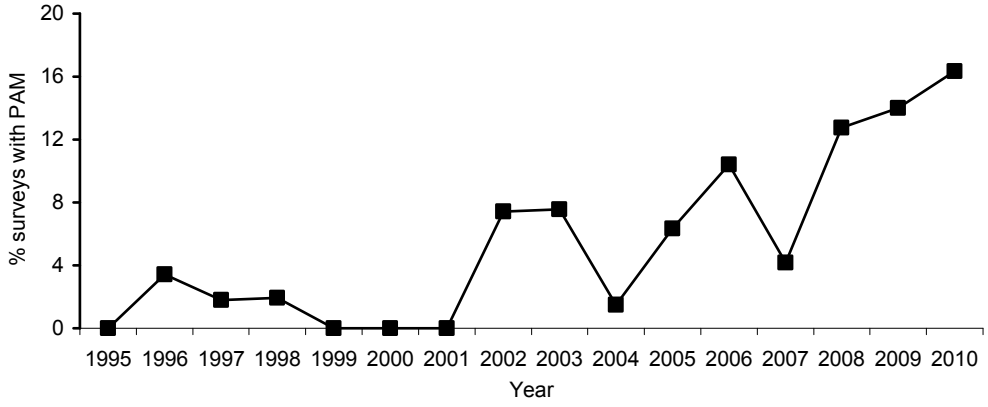

Figure 3.4. Percentage of surveys using PAM from 1995 to 2010.

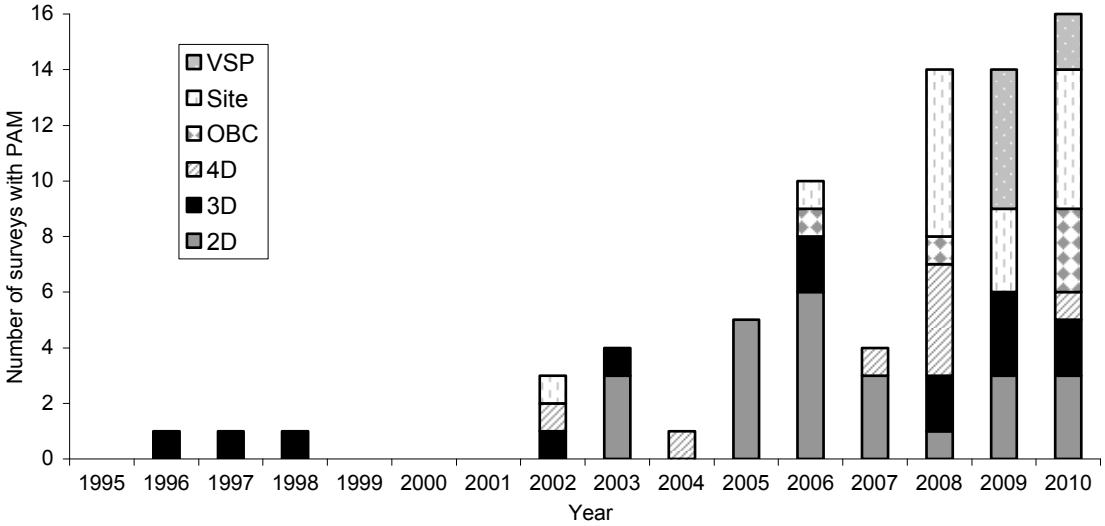

Figure 3.5. Use of PAM on different types of survey, 1995-2010.

PAM was used mostly in areas of importance for marine mammals and deep water areas where deep-diving species that remain submerged for prolonged periods may be found. Most surveys with PAM were to the west and north of Shetland where deep waters occur (Table 3.20). Others were located in the northern North Sea and the Outer Moray Firth (adjacent to the Moray Firth Special Area of Conservation [SAC]), with fewer surveys with PAM in the central North Sea and in the deep waters of the Rockall area. Although Rockall is a sensitive area, there have been few surveys there in recent years when PAM has been more commonly utilised. There was one survey with PAM in St George's Channel, close to the Cardigan Bay SAC. No surveys used PAM in the southern North Sea, where sensitivities are lower. PAM was more commonly used during the summer, reflecting the prevalence of surveying then (Figure 3.6).

Table 3.20. Location of surveys using PAM, 1995-2010.

Area	Number of surveys using PAM
Deep waters west and north of Shetland	53
Northern North Sea	9
Outer Moray Firth	7
Central North Sea	3
Rockall	3
St George's Channel	1

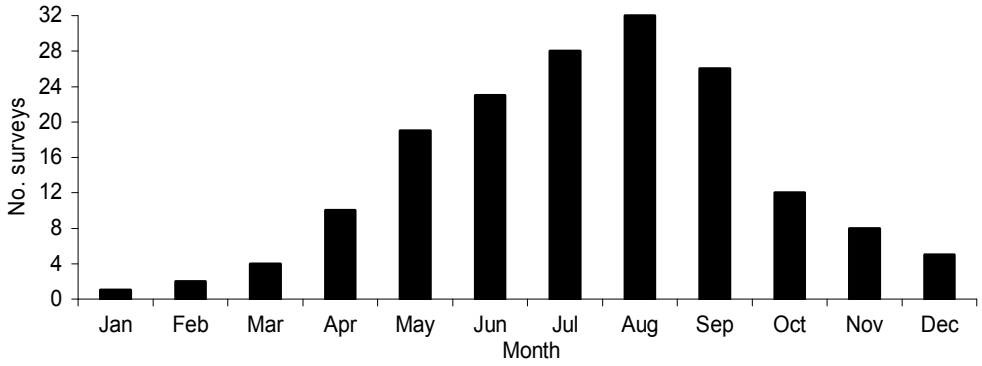

Figure 3.6. Number of surveys using PAM per month, 1995-2010 (surveys spanning more than one month have been included for each month that PAM was used).

PAM is logistically more complex than visual observations, as is reflected in the time spent monitoring. On 61% of surveys using PAM (where effort was recorded) hours of visual observations exceeded those of acoustic monitoring. This also reflects the difference in the use of each monitoring method, as some surveys used PAM primarily or only during hours of darkness; as surveying peaked during the summer months (section 3.8.2) hours of darkness were fewer than the hours of daylight available for visual monitoring. On 22 of 31 surveys using PAM in 2009 and 2010, PAM was used both during the night and the day, while eight used PAM only during hours of darkness (on one survey the times were unknown).

In recent years (2009 and 2010) the PAM array was deployed from the source vessel (in earlier years deployment was often from the chase boat). Sometimes several deployment options were attempted before finding one that worked. On static platforms (e.g. during VSP operations) the PAM array was suspended vertically from a suitable attachment point (e.g. a derrick). On moving vessels deployment was usually from one side of the stern, often attached to the lead-in of a streamer. Sometimes the PAM array was deployed centrally from the stern, with the PAM cable between or under the airgun array(s) and the hydrophones behind the airguns. With central deployment (and sometimes side

deployment) the PAM array had to be recovered if the airguns were brought on board and could only be redeployed after the airguns. Sometimes centrally-deployed PAM arrays also had to be recovered during turns to avoid entanglement with the airguns and could not be redeployed until the vessel was heading straight. Line changes often had to be extended at night to allow acoustic monitoring after redeployment of the PAM array (even then the pre-shooting search was still too short for 12% of survey lines). Deployment issues in at least one case were attributed to lack of equipment (a boom) on the survey vessel.

There were six instances (on three surveys) in 2009 and 2010 when the PAM array became entangled in the seismic equipment. On three occasions a centrally-deployed PAM array became entangled in the airguns; each time the PAM cable was severed and had to be replaced. With side deployment there were three occasions when the PAM cable became entangled in the lead-in, once requiring a replacement. The risk of entanglement increased in poor weather conditions; sometimes the PAM array was recovered during these conditions and there was no monitoring for marine mammals.

A variety of software was used for displaying acoustic detections of marine mammals, often in combination. Of the 31 surveys using PAM in 2009 and 2010, 10 used IFAW software (Rainbow Click, Porpoise and/ or Whistle), 15 used Ishmael and 24 used PAMGuard. There were a few problems with the software, including repeated crashes and false detections due to noise interference (it should be remembered that the software has been developed further since the period covered by this report).

PAM operators sometimes commented on the lack of availability or ineffectiveness of UHF radios for communicating with MMOs and/ or the seismic crew. For ease of communication some operators preferred the PAM monitoring station to be on the bridge in close proximity to the MMOs, although the availability of this option will vary between vessels.

3.6.2 Use of PAM for operations commencing at night

Since 2005, there has been a decrease in the number of times airguns commenced firing at night without PAM and a corresponding general upwards (although more erratic) trend in the number of starts at night with PAM, although overall firing commenced at night without PAM more often than with PAM in all years (Figure 3.7). The use of PAM when starting firing at night varied geographically, with PAM being used for the majority of start-ups at night in the west of Shetland and Rockall areas in recent years (Figure 3.8). Its use at night was also prevalent in the Outer Moray Firth and to the north of Shetland in some years, but it was used less often in the northern and central North Sea. PAM was not used at night in the southern North Sea (even though there was considerable survey effort) or the Irish Sea.

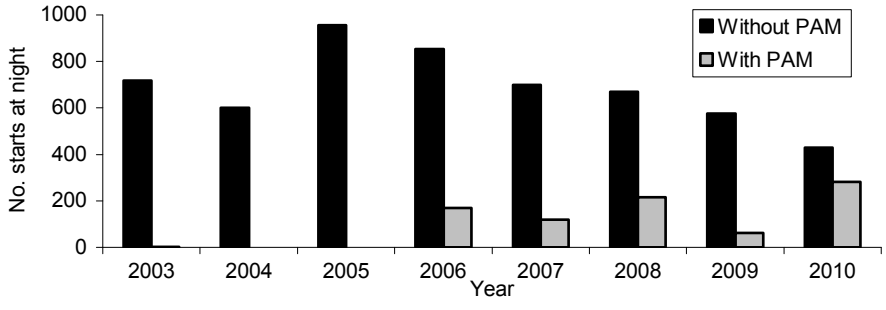

Figure 3.7. Number of times airguns commenced firing at night within the UKCS with and without PAM.

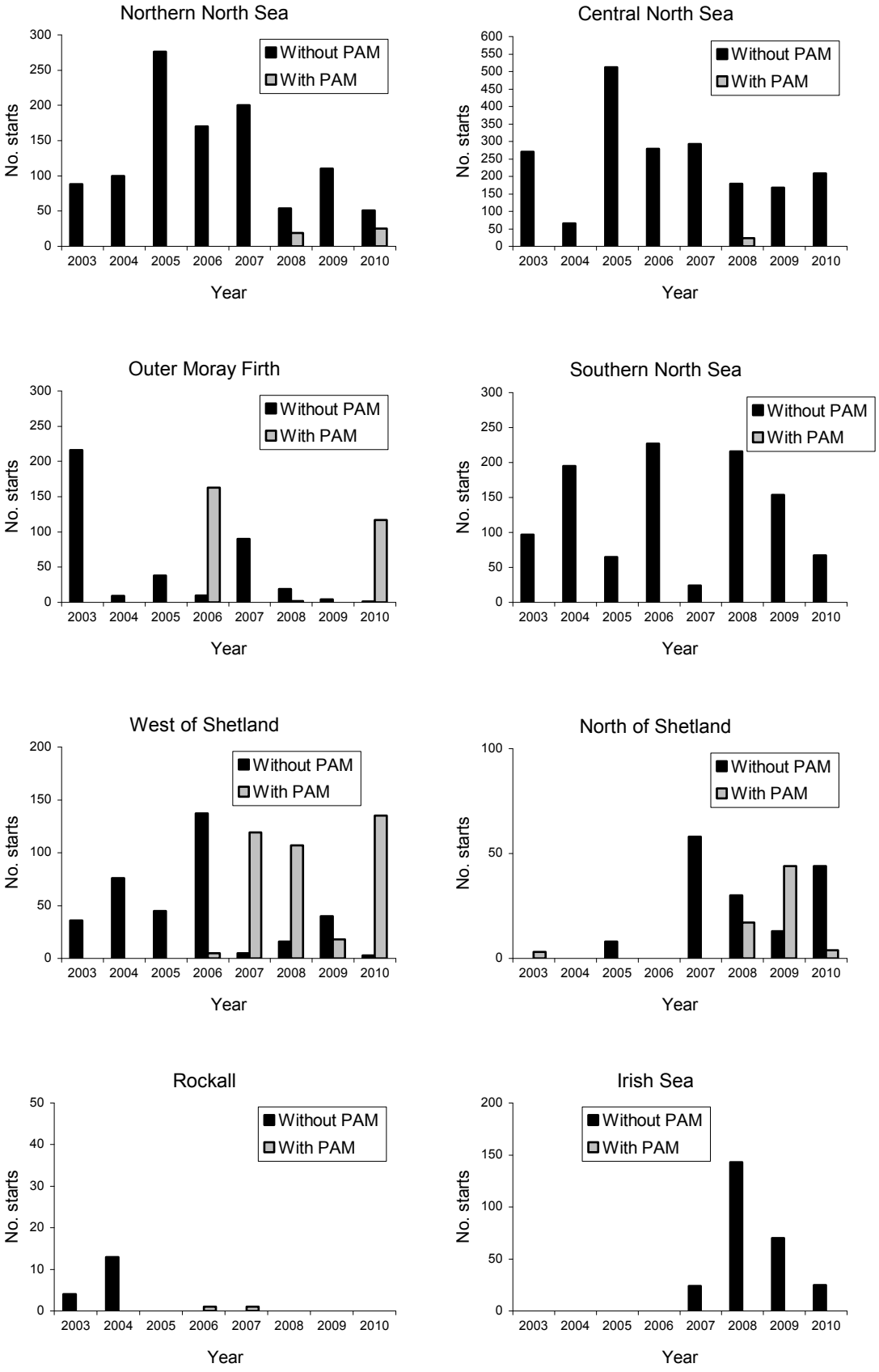

Figure 3.8. Number of times airguns commenced firing at night with and without PAM in different areas of the UKCS.

On most survey types firing at night commenced more often without PAM than with PAM (Figure 3.9). PAM was used for start-ups at night mainly on 3D and 4D surveys. The only surveys where start-ups at night with PAM exceeded those without were 3D surveys in 2010 and 4D surveys in 2008. Site surveys and VSP operations have fewer start-ups, but often there seemed to be no attempt to schedule operations to start during daylight. Occasionally equipment problems delayed operations that should have commenced in daylight until night-time. During 2009 and 2010 a few site surveys and VSP operations only commenced firing at night; conversely, on one site survey the crew waited until daylight to recommence following equipment problems and on another they tried to avoid starting at night.

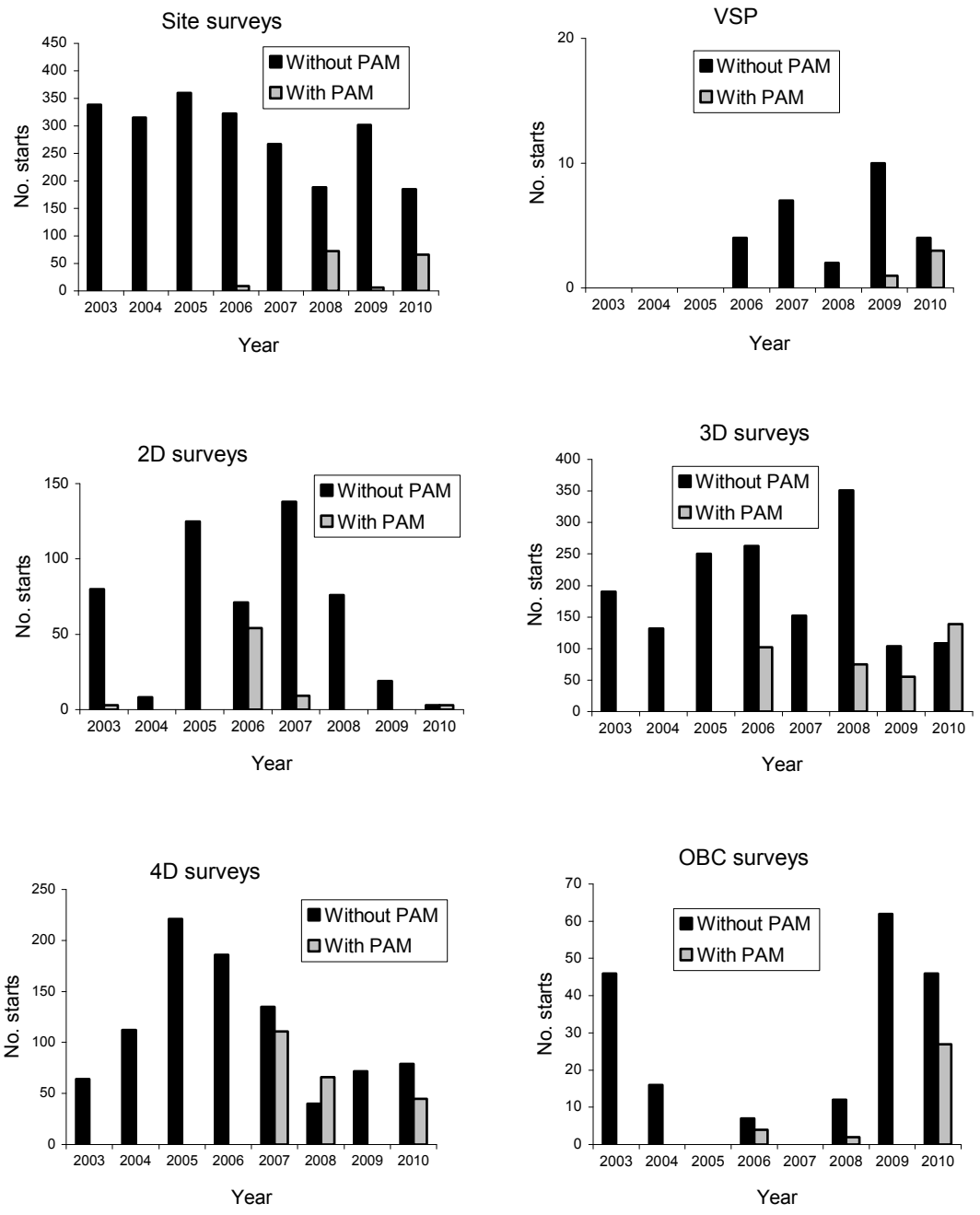

Figure 3.9. Number of times airguns commenced firing at night within the UKCS with and without PAM, for different survey types.

On 295 occasions acoustic monitoring at night was accompanied by visual monitoring at dusk and dawn. Cetaceans were detected acoustically on 41 nights, but visual sightings occurred in the accompanying two hours prior to dusk only twice. Similarly, of 17 occasions when cetaceans were seen during the two hours prior to dusk, in only two cases were there acoustic detections during the following night. Both results confirmed marine mammal presence or absence at dusk is not a reliable indicator to inform start-up decisions at night.

3.6.3 Use of PAM for operations commencing in poor weather

On average firing commenced in suboptimal weather conditions on 680 occasions each year, equating to a minimum of 28% of start-ups, as weather was not always recorded. On most survey types firing commenced in suboptimal weather more often without PAM than with PAM (Figure 3.10). PAM was mainly used on 3D and 4D surveys; only on these survey types in 2010 did firing commence in suboptimal weather more often with PAM than without. Other survey types rarely used PAM prior to starting in suboptimal weather conditions.

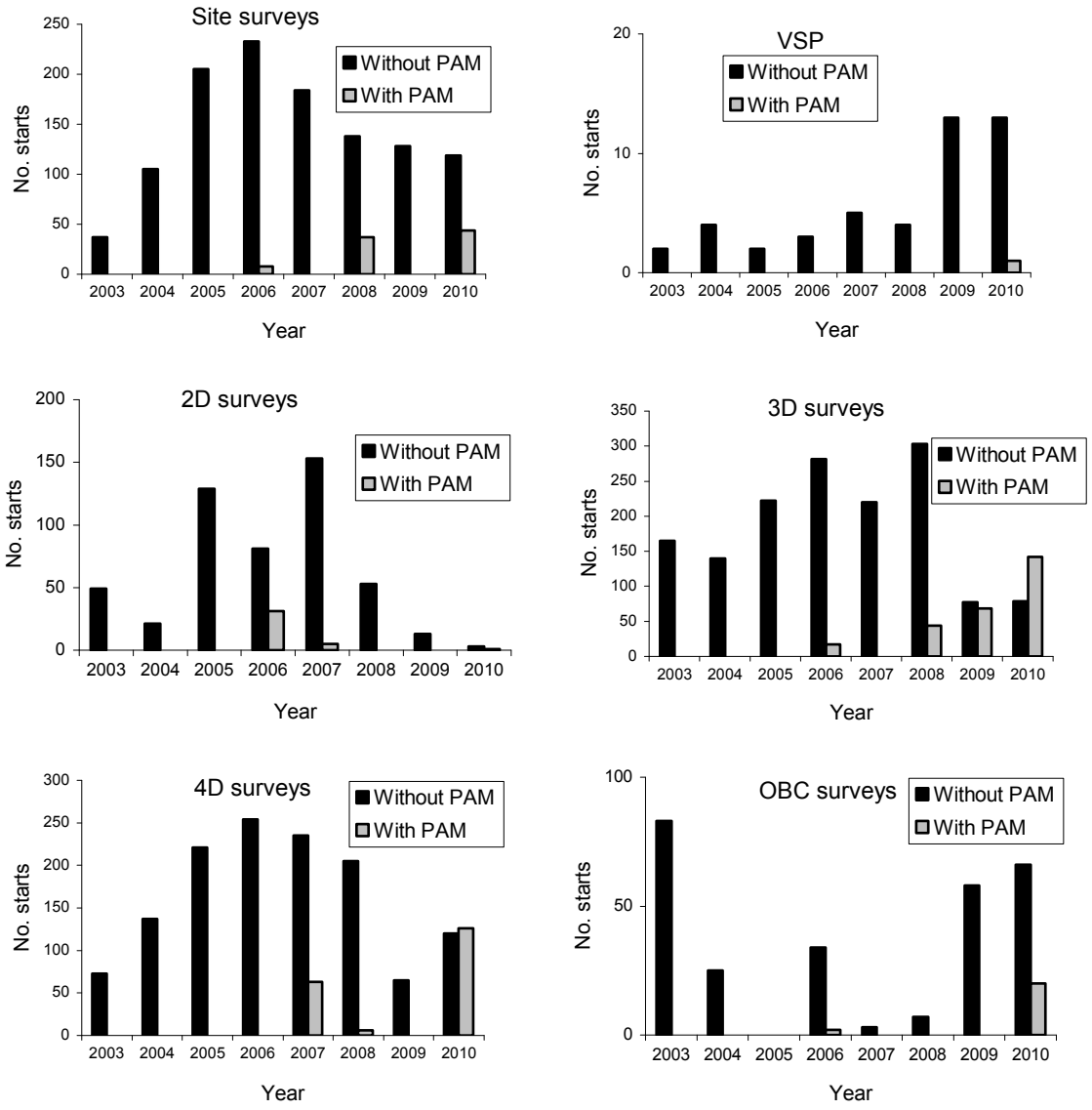

Figure 3.10. Number of times airguns commenced firing in suboptimal weather within the UKCS, with and without PAM.

In comparison, during very poor weather conditions the average number of occasions when firing commenced was 131 per year (5% of start-ups; again this is a minimum percentage). Again operations mostly commenced without PAM, although in recent years there was more use of PAM during very poor weather on site, 3D and 4D surveys (Figure 3.11).

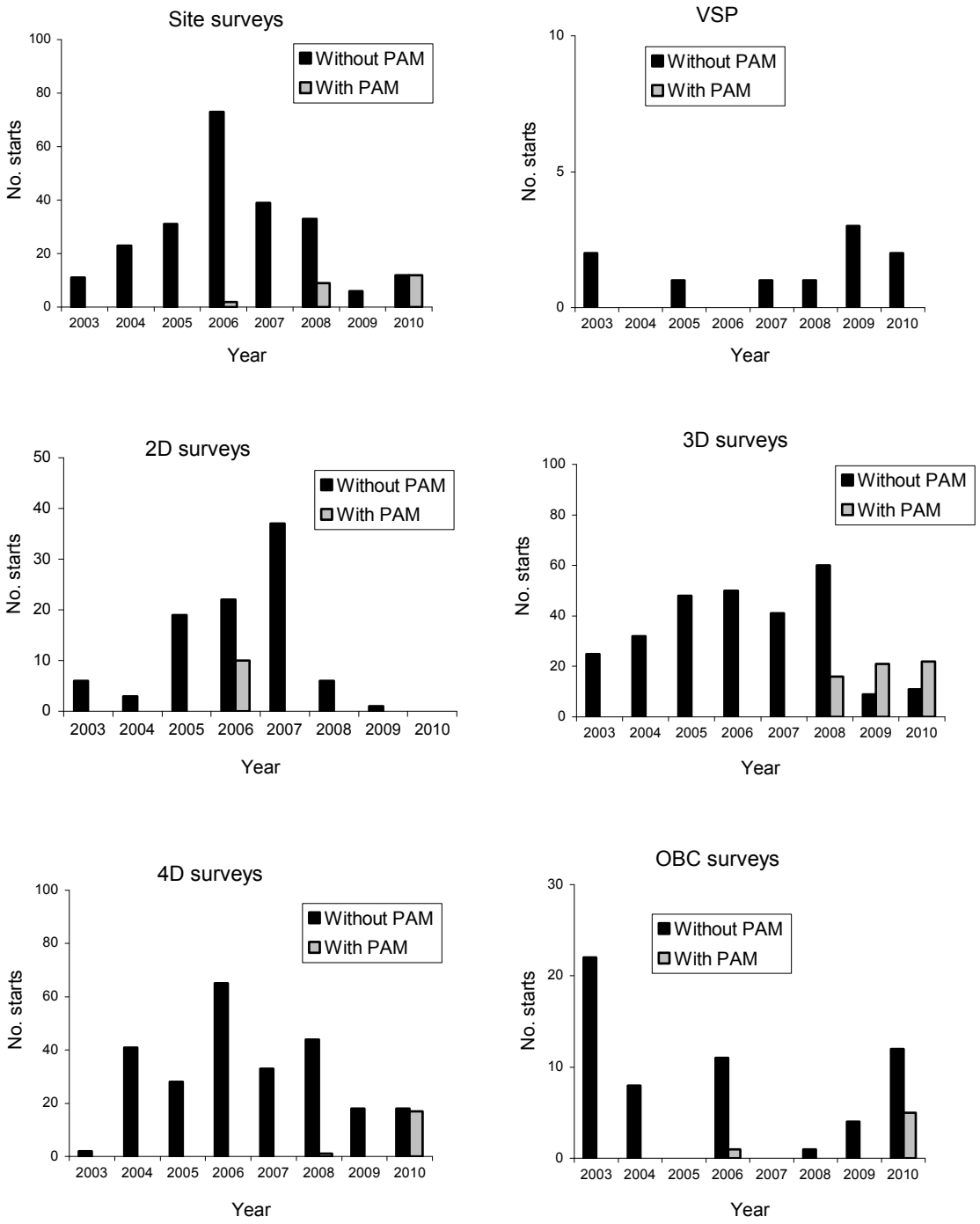

Figure 3.11. Number of times airguns commenced firing in very poor weather within the UKCS, with and without PAM.

3.6.4 Detection rates using PAM compared to visual sighting rates

There were 772 acoustic detections, most being unidentified dolphins, sperm whales or harbour porpoises (Table 3.21). For most species identification was only possible if there was visual confirmation. Without this, identification was limited to sperm whale or harbour porpoise or the less specific groups of cetacean, delphinid or dolphin. Five mixed species detections (confirmed visually) involved long-finned pilot whales in association with dolphins (where identified, Atlantic white-sided dolphins). There was only one confirmed detection of a baleen whale, although the medium whale detected may have been a minke whale.

Table 3.21. Acoustic detections of marine mammals, 1995-2010.

Species	Number of acoustic detections
Cetacean sp.	45
Blue/ fin/ sei whale	1
Sperm whale	155
Medium whale sp.	1
Long-finned pilot whale	14
Killer whale	1
Long-finned pilot/ false killer whale	1
Delphinid sp. (dolphin/ long-finned pilot / killer / false killer whale)	9
Dolphin sp.	309
Bottlenose dolphin	1
Risso's dolphin	4
Patterned dolphin (common/ striped/ white-beaked/ Atlantic white-sided)	2
White-beaked dolphin	20
Atlantic white-sided dolphin	57
Lagenorhynchus spp.	3
Short-beaked common dolphin	11
Harbour porpoise	143
Total	**772***

*includes some mixed species detections

On surveys where PAM was used the number of acoustic detections compared to visual sightings varied; some surveys had reasonable numbers of acoustic detections while others had few or none. When PAM was concurrent with visual observations there were sometimes no detections apparent on the PAM software when marine mammals, particularly dolphins, were seen. There was no apparent correlation of the number of acoustic detections (compared to visual sightings) with the experience of the PAM operator. Some reports referred to problems with interference from background noise, such as cavitation of propellers, swell and the use of thrusters (the latter being a common problem on static platforms used for VSP).

For animals at any range, visual sighting rates were significantly higher than acoustic detection rates for all cetaceans combined, sperm whales and Atlantic white-sided dolphins (Figure 3.12,Table 3.22). When considering only those animals within the mitigation zone, the results showed that visual monitoring was significantly better than PAM at detecting marine mammals in the mitigation zone for Atlantic white-sided dolphins and the groups of all small odontocetes, all delphinids and all cetaceans (Figure 3.13,Table 3.22).

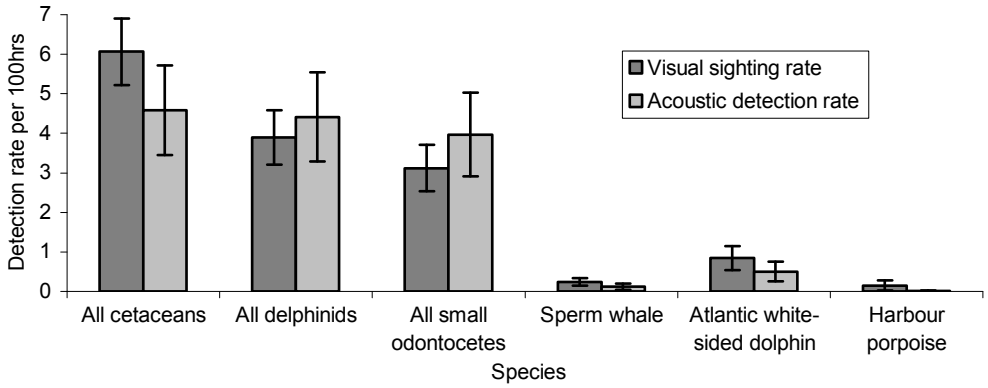

Figure 3.12. Mean detection rate (and standard error) per 100 hours monitoring for visual and acoustic monitoring.

Table 3.22. Statistical significance of difference in detection rate of marine mammals in relation to monitoring method using 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; n.s. = not significant).

Species	z	T^+	n	P
At any range				
All cetaceans combined	3.752	-	141	< 0.001
All delphinids combined	0.693	-	108	n.s.
All small odontocetes combined	-0.257	-	99	n.s.
Sperm whale	-	55	11	< 0.05
Atlantic white-sided dolphin	2.999	-	16	< 0.01
Harbour porpoise	-	5	3	n.s.
Within the mitigation zone				
All cetaceans combined	4.914	-	44	< 0.001
All delphinids combined	3.907	-	34	< 0.001
All small odontocetes combined	2.571	-	24	< 0.01
Atlantic white-sided dolphin	-	40	9	< 0.05

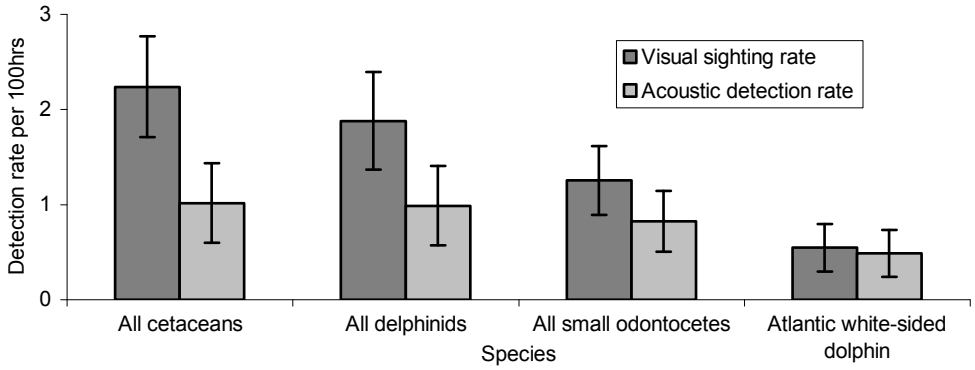

Figure 3.13. Mean detection rate (and standard error) within the 500m mitigation zone per 100 hours monitoring for visual and acoustic monitoring.

When visual monitoring and PAM were concurrent, 52% of detections were only visual, 20% were only acoustic and 28% were detected both visually and acoustically, confirming the increased effectiveness of visual monitoring. However, this also highlights that there are some occasions when animals are only detectable with PAM.

3.6.5 Range estimation using PAM

There was no estimation of range on 65% of occasions when animals were only detected acoustically (compared to 10% of occasions when animals were detected visually), highlighting the difficulty of range estimation using PAM. For acoustic detections without visual confirmation the estimated range was often a multiple of 250m, suggesting a lack of accuracy. For animals judged to be within 1km of the airguns, the proportion of detections where range was more detailed than to the nearest 250m was much greater for visual sightings than acoustic detections (Table 3.23). At greater distances the accuracy of range estimation decreased for both monitoring methods, but visual sightings more often had an estimated range more detailed than to the nearest 250m. Accuracy of range estimation for animals detected by both monitoring methods was similar to those only detected visually.

Table 3.23. Minimum proportion of detections where range was more detailed than to the nearest 250m for animals detected by visual or acoustic means or both.

Method of detection	Range up to 1km from airguns	Range more than 1km from airguns
Acoustic only	27.5%	1.1%
Visual and acoustic	70.3%	25.5%
Visual only	76.1%	24.1%

Marine mammals were detected out to considerable distances, although 99% were detected within 6km of the airguns, whether detected visually or acoustically (Figure 3.14). However, while 38% of visual sightings occurred within the 500m mitigation zone, only 14% of acoustic detections were within this zone (Kolmogorov-Smirnov test: χ^2 approximation = 47.141, d.f. = 2, $p < 0.001$).

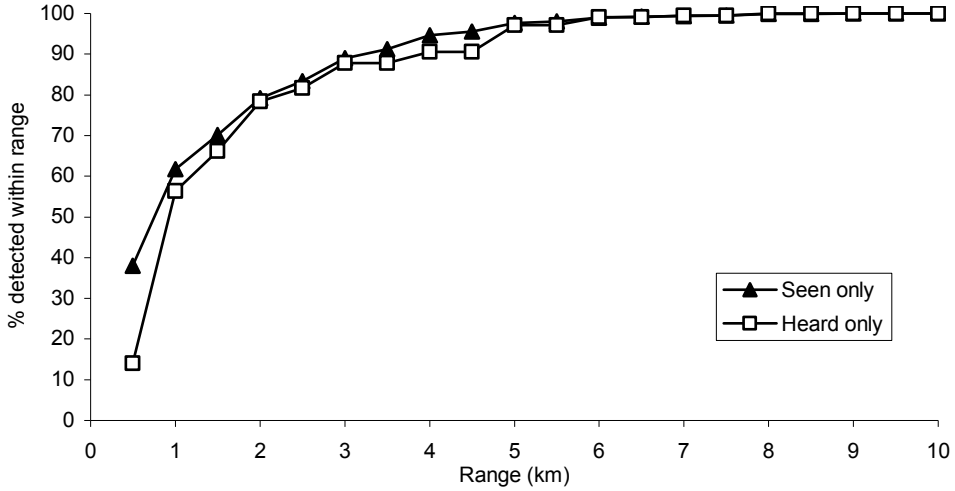

Figure 3.14. Proportion of detections of marine mammals within a given range of the airguns, for animals detected by visual means alone or by acoustic means alone (using only detections where range was estimated).

3.6.6 Delays in firing when using PAM

Of the 165 occasions within the UKCS between 1995 and 2010 when a delay in firing was required due to the presence of marine mammals in the mitigation zone, 13 were due to

animals that were detected only acoustically; of these eight were detected during the hours of darkness when visual monitoring was not possible.

On surveys where both PAM and visual monitoring were used, although most delays were required for animals detected visually, the rate at which delays were required was slightly increased for acoustic detections (2.08 delays required per 1,000 hours acoustic monitoring and 1.28 delays required per 1,000 hours visual observations). However, the frequency of delays did not differ significantly between the monitoring methods (χ^2 = 2.951, d.f. = 1).

The closest distance of the animals from the airguns was not recorded for 85% of occasions when a delay was required following a detection made only acoustically. However, just over half of these instances involved detections of harbour porpoises, which it could be assumed would be in close proximity, due to the rapid attenuation of high frequency porpoise vocalisations and consequent inability of PAM equipment to detect harbour porpoises more than a few hundred metres from the hydrophones. The remaining instances where range was not estimated involved unidentified dolphins, where presumably the PAM operator judged from the strength of the signal that the animals were likely to be nearby. On only 2% of occasions when delays were required due to animals detected visually was there no recorded distance from the airguns. Delays were correctly implemented on 55% of occasions when a delay was required following a visual detection of marine mammals in the mitigation zone; for acoustic detections this proportion rose to 77% (assuming that animals were outside the mitigation zone if range was not estimated and there was no delay).

3.7 MMOs and PAM operators

3.7.1 Dedicated observers, non-dedicated observers and PAM operators

MMOs are used on all seismic surveys within the UKCS but only on some surveys are they dedicated to this role. The use of dedicated MMOs has increased since the guidelines were introduced (Figure 3.15). In earlier years dedicated MMOs were uncommon and where they were used there was only one on a vessel. By 2010 dedicated MMOs were more common, sometimes with two on each vessel.

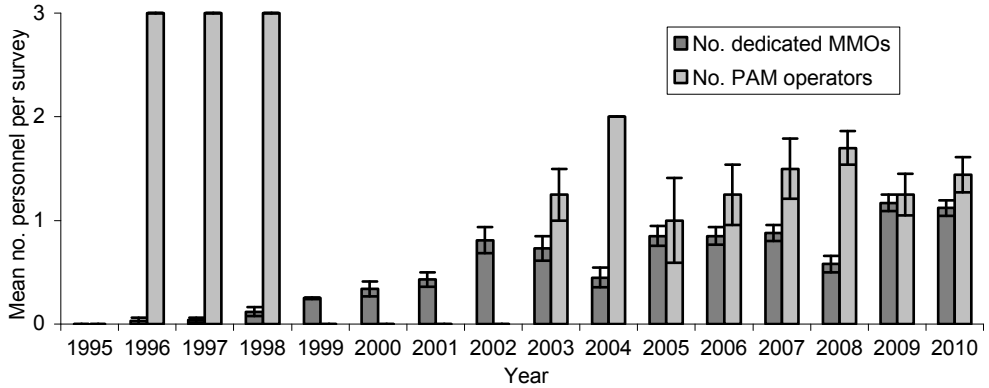

Figure 3.15. Mean number (and standard error) of dedicated MMOs (all surveys) and PAM operators (only surveys where PAM was used) per survey over time (UKCS only).

PAM trials over three years after the introduction of the guidelines used a relatively high number of PAM operators, after which PAM was not used for several years. When its use resumed the number of PAM operators per survey with PAM varied (Figure 3.15).

The number of dedicated MMOs per survey increased very slightly during the summer, when longer daylight hours permitted more visual observations, while the number of PAM operators varied (Figure 3.16). The number of dedicated MMOs per survey was also higher in northern areas (Figure 3.17), where daylight hours during the summer were longest, and was lower in southern areas. By 2010 all surveys between 1 April and 1 October north of 57^{o} latitude had two MMOs (dedicated or non-dedicated). PAM operators were used almost exclusively in northern areas (Figure 3.17). Of the 22 surveys using PAM both during the day and at night in 2010, 15 had two PAM operators while seven had only one. Of the eight surveys in 2010 where PAM was only used at night only one had two PAM operators, this taking place during November and December when hours of darkness would have been prolonged. There were at least two VSP operations (and possibly one site survey) in 2009 and 2010 where one person doubled up as MMO and PAM operator.

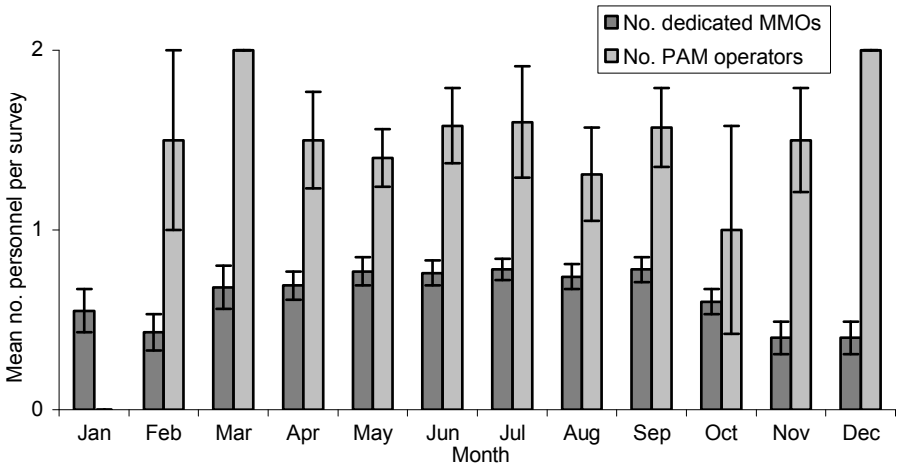

Figure 3.16. Mean number (and standard error) of dedicated MMOs (all surveys) and PAM operators (only surveys where PAM was used) per survey in relation to month of commencement of the survey (UKCS only).

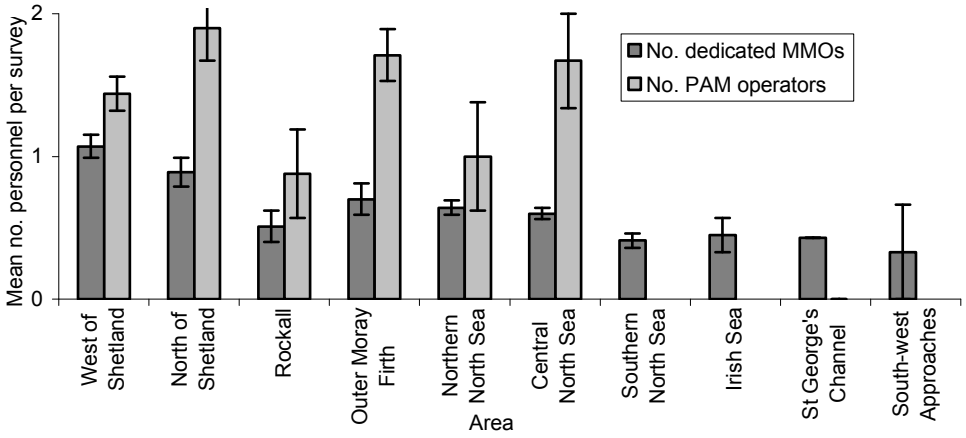

Figure 3.17. Mean number (and standard error) of dedicated MMOs (all surveys) and PAM operators (only surveys where PAM was used) per survey in different areas of the UKCS.

Dedicated MMOs were used more often on 2D, 3D, 4D and OBC surveys than on site surveys and VSP operations (Figure 3.18). By 2010 all 2D, 3D, 4D and OBC surveys had dedicated MMOs. Where PAM was used on VSP operations the number of PAM operators was often lower (Figure 3.18), probably due to the limited duration of these operations (often only lasting for around 24 hours).

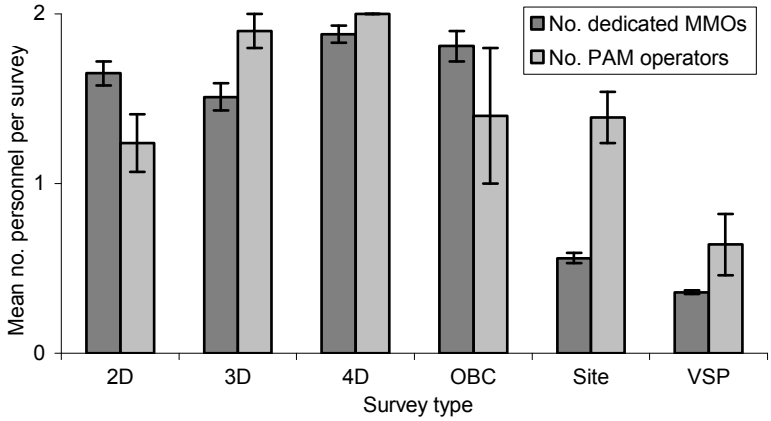

Figure 3.18. Mean number (and standard error) of dedicated MMOs (all surveys) and PAM operators (only surveys where PAM was used) per survey on different types of survey (UKCS only).

Dedicated MMOs had higher sighting rates of marine mammals than non-dedicated MMOs (Table 3.24), even during good weather conditions. The rate at which delays were required was also higher for dedicated MMOs than for non-dedicated MMOs and delays were more often implemented correctly. When dedicated MMOs were used there was an increase in the percentage of adequate daylight pre-shooting searches and soft starts (Table 3.24).

Table 3.24. Observations and implementation of the guidelines by dedicated and non-dedicated MMOs.

	Dedicated MMOs	Non-dedicated MMOs
Sighting rate per 100hrs (all weather)	4.03	1.29
Sighting rate per 100hrs (good weather)	5.71	2.15
% adequate pre-shooting searches during daylight	89.7%	66.3%
% soft starts >= 20 mins (all survey types)	71.9%	34.2%
Number of delay situations per 1,000hrs watch	0.95	0.25
% occasions when delays were correctly implemented	62.2%	33.3%

Dedicated MMOs supplied higher quality data than non-dedicated MMOs (Table 3.25). Effort and operations data recorded by PAM operators were often missing or of insufficient quality to include in the database. Weather information was most often complete when dedicated MMOs were used; PAM operators often didn't record weather conditions, even though less information was required for PAM. A higher proportion of sightings records had accompanying effort data when dedicated MMOs were used; many acoustic detections and visual sightings by non-dedicated MMOs had no accompanying effort data.

Table 3.25. Quality of data recorded by dedicated MMOs, non-dedicated MMOs and PAM operators.

	Dedicated MMOs	Non-dedicated MMOs	PAM operators
% surveys where operations data were of sufficient quality to include in database	96.8%	87.1%	74.3%
% surveys where effort data were of sufficient quality to include in database	95.0%	76.5%	56.8%
% surveys where sightings data were of sufficient quality to include in database (sightings/ detections known to have occurred)	97.7%	93.8%	97.5%
% effort records with sea state, swell and visibility recorded	99.3%	75.3%	-
% effort records with sea state and swell recorded	-	-	60.9%
% sightings/ detections with accompanying effort data	79.6%	46.2%	56.0%

3.7.2 Benefits of relevant prior experience

Dedicated MMOs with marine mammal experience prior to becoming an MMO had higher sighting rates of marine mammals than those without prior experience and could detect animals at greater distances (Table 3.26), both of which indicate better detection skills. Those with prior experience observed a wider range of behaviours and recorded slightly more behaviours per sighting. Both groups provided adequate weather information.

Table 3.26. Quality of observations of dedicated MMOs with and without prior marine mammal experience.

	MMOs with prior marine mammal experience	MMOs without prior marine mammal experience
Sighting rate per 100hrs (all weather)	8.10	2.69
Sighting rate per 100hrs (good weather)	11.69	4.74
Mean closest distance of approach of animals (all weather)	1,519 m	919 m
Mean closest distance of approach of animals (good weather)	1,594 m	1,063 m
Mean range of behaviours observed	14.0	8.2
Mean number of behaviours per sighting	1.6	1.4
% effort records with sea state, swell and visibility recorded	99.1%	96.4%

3.8 Trends in operations and compliance over time

3.8.1 Trends in operations over time

The number of surveys within the UKCS appears to have increased over time (Figure 3.19). Since 2003 the increase was mainly in site surveys and VSP operations (Figure 3.20; limited information exists in the database regarding survey types prior to 2003). This is assessed solely by the number of surveys within the JNCC MMO database and may reflect an actual increase in the number of surveys or increased reporting of surveys or both. Trends to some extent reflect trends in consents granted, although many reports (particularly for site surveys) were missing in some earlier years (e.g. Stone 2003, 2006), while in 2009 and 2010 almost all reports were submitted to JNCC. The increase in the number (or increased reporting) of site surveys and VSP operations is reflected in the increased proportion of surveys with airgun volumes below 500 cu. in. (Figure 3.21). In earlier years airgun volumes were not always reported, but from available information there were no clear trends in the volume of airguns used, except that the maximum volume used on VSP operations increased in recent years (Figure 3.22).

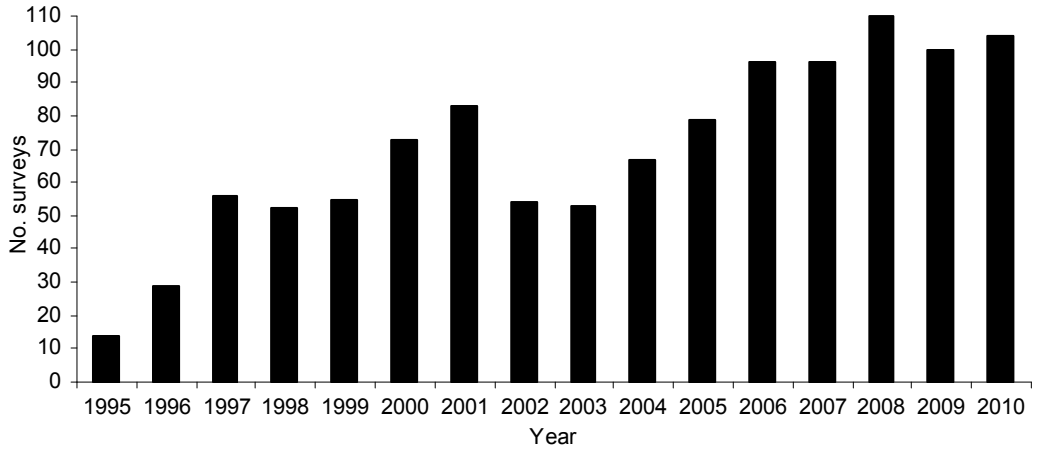

Figure 3.19. Number of seismic surveys within the UKCS over time.

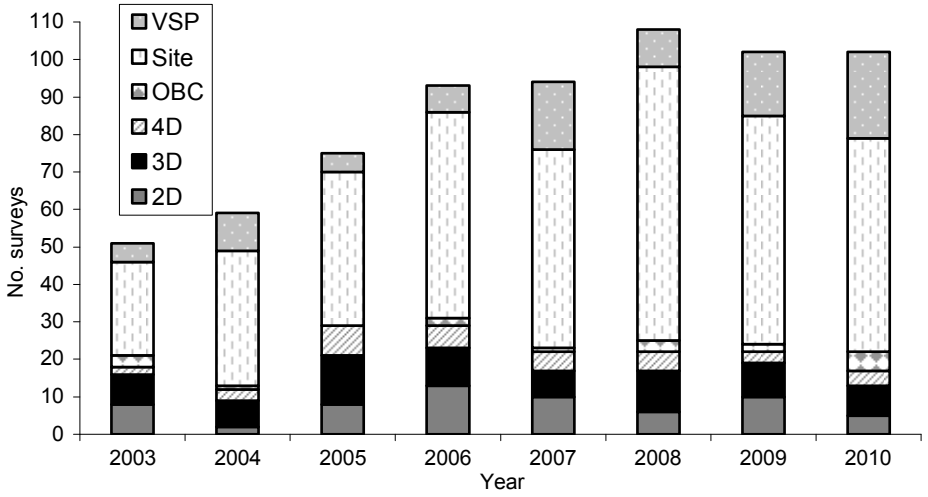

Figure 3.20. Number of seismic surveys of different types from 2003-2010.

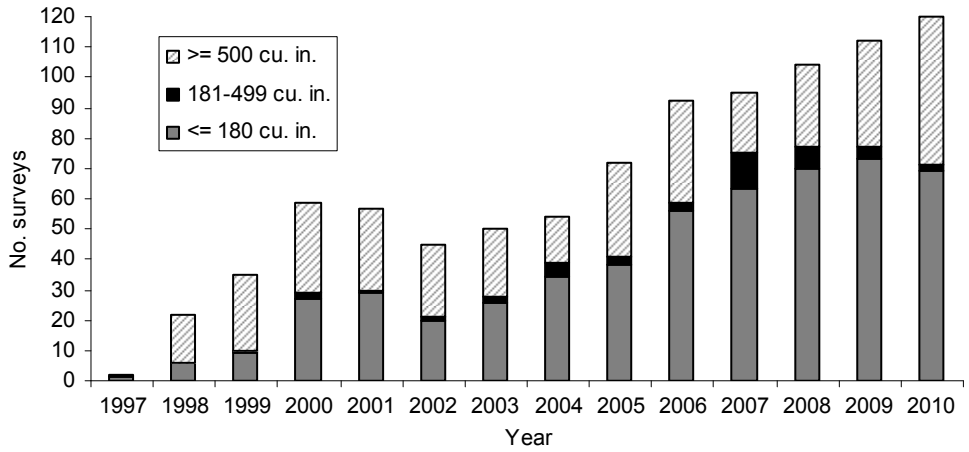

Figure 3.21. Number of surveys with airgun volumes <= 180 cu. in., >= 500 cu. in. or in between.

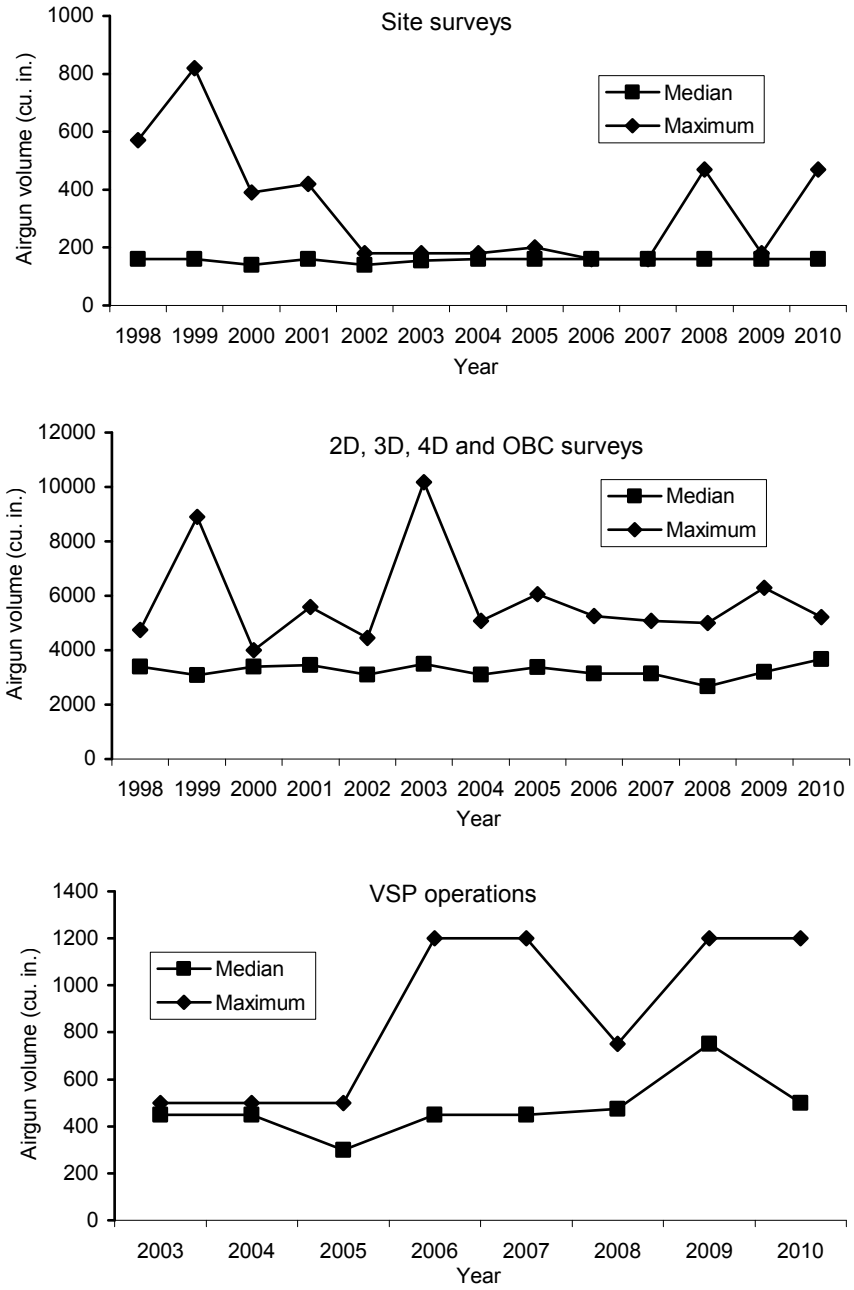

Figure 3.22. Median and maximum volume of airguns (cu. in.) per year (few data were available for VSP operations prior to 2003).

Surveying was consistent over time in the northern North Sea, the southern North Sea and to the north of Shetland, albeit with some peaks and troughs, while surveys in the central North Sea increased (Figure 3.23). For some other areas peaks in the incidence of seismic surveying coincided with offshore oil and gas licensing rounds; surveys to the west of Shetland, in St George's Channel and the Irish Sea peaked in the mid 1990s, coinciding with the 16th round of offshore licensing, while in the Rockall area surveys were mostly in 1997 and 1998 when exploration licenses were granted for the Atlantic Margin in the 17th round. In recent years there has been another small increase in surveys in the Irish Sea. In the Outer Moray Firth a small peak in surveys occurred in 2003. There were only two surveys in the South-west Approaches, in 1998 and 2001.

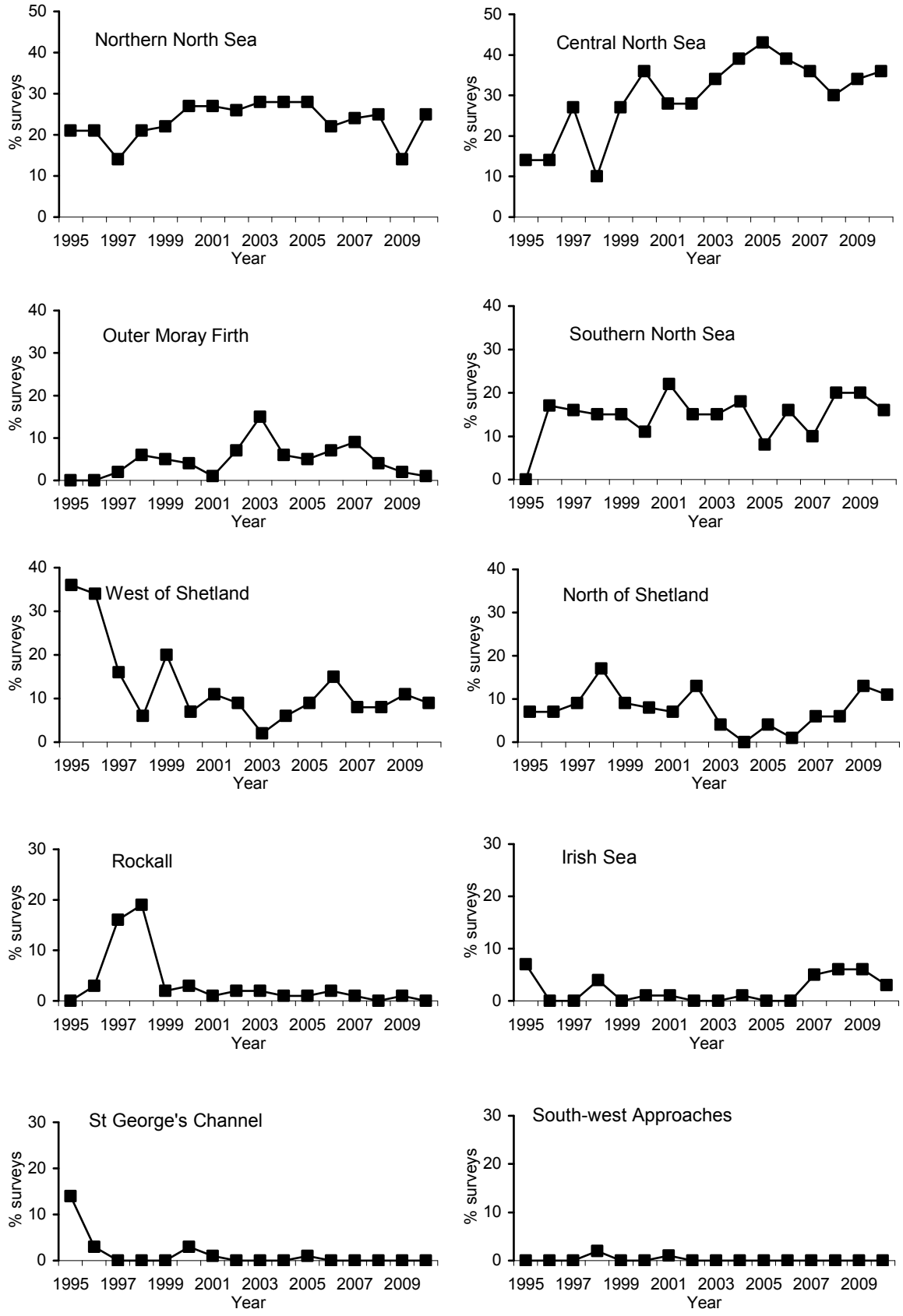

Figure 3.23. Proportion of surveys occurring in different geographic areas, as a percentage of all surveys within the UKCS each year.

3.8.2 Seasonal variation in operations

Surveys were seasonal, particularly in exposed areas where rough seas and large swell may be expected during the winter. Surveys in the northern and central North Sea, west and north of Shetland and Rockall commenced mostly during the summer (Figure 3.24). Less pronounced seasonal variation was evident in the southern North Sea, with little variation in the Irish Sea, St George's Channel, the Outer Moray Firth and the South-west Approaches.

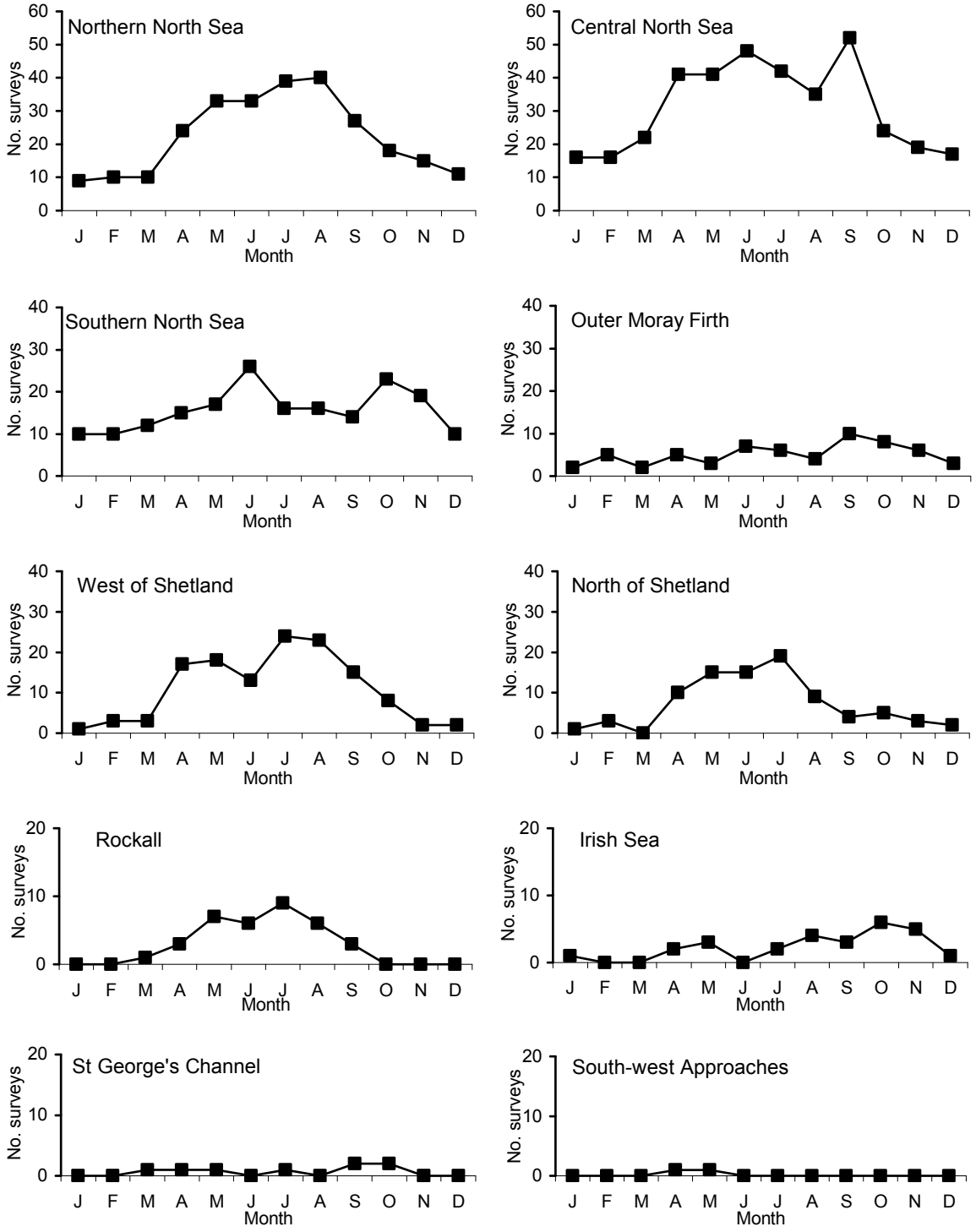

Figure 3.24. Seasonal variation of surveys in different geographical areas of the UKCS, based on month of commencement of surveys (all years combined).

Seasonal variation in operations was evident for all types of seismic survey, although it was less pronounced for VSP operations and OBC surveys (Figure 3.25Figure 3.25). VSP operations and site surveys continued through the winter, albeit in lower numbers than in the summer. There were very few surveys that typically have large airgun arrays (and often tow large spreads of streamers) in the winter, when weather conditions may be expected to be poor.

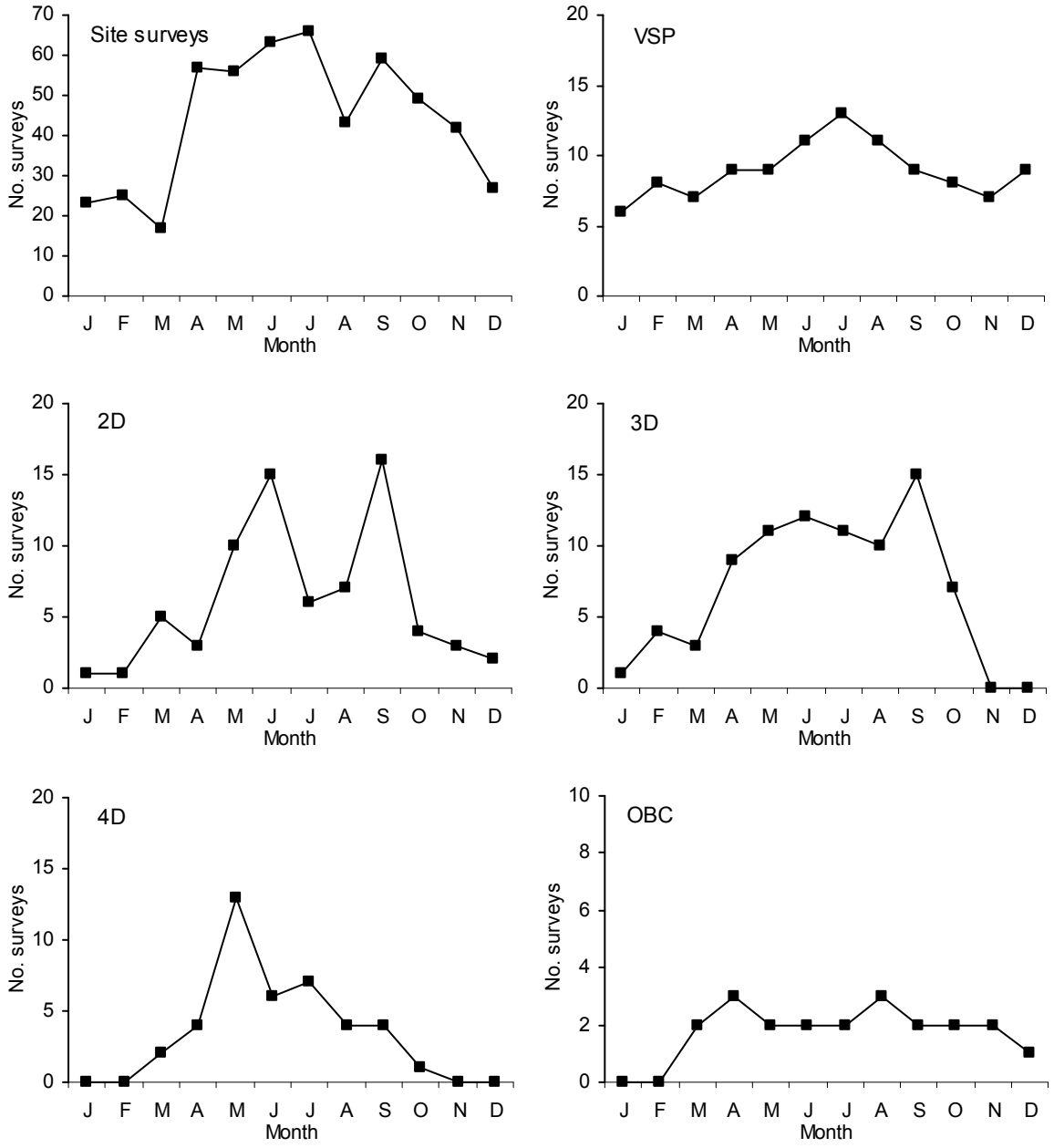

Figure 3.25. Seasonal variation of different types of seismic surveys, based on month of commencement of surveys (all years combined).

3.8.3 Trends in compliance over time

The proportion of adequate pre-shooting searches has shown no major trends over time, ranging between 76% and 95%. The proportion of adequate soft starts has increased since

2004 (Figure 3.26), largely due to improvements on site surveys and VSP operations as alternative methods of performing a soft start are now available. Prior to this, on most site surveys no soft start was undertaken even though this was not always agreed with the regulator and JNCC.

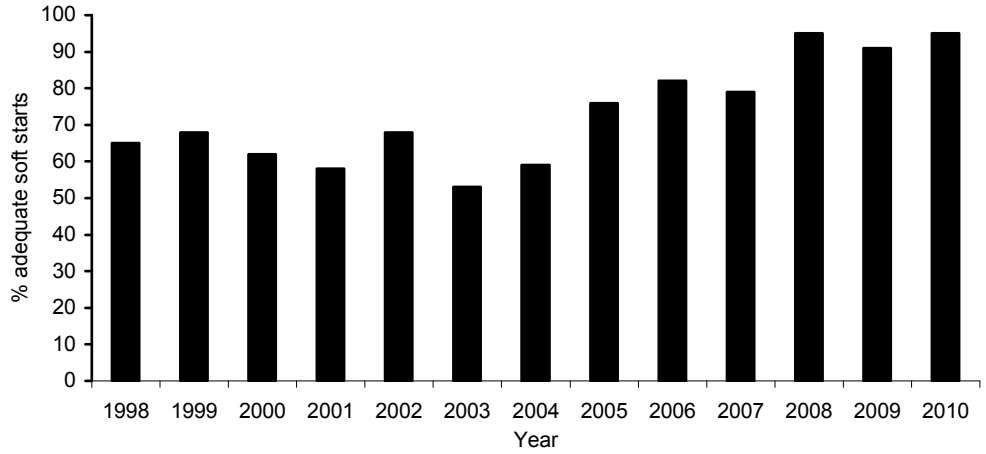

Figure 3.26. Proportion of adequate soft starts within the UKCS over time (all survey types).

The level of compliance with the requirement to delay firing was highly variable between years (Figure 3.27), partly as a result of the low sample size. As there were only a small number of delays each occasion when the correct procedures were or were not implemented resulted in a substantial raising or lowering of the proportion where there was compliance for that year. Although highly variable, overall compliance with the requirement to delay firing if marine mammals are in the mitigation zone has shown a general improvement over time (Figure 3.27), although the level of compliance with this aspect of the guidelines still lags behind that of pre-shooting searches and soft starts.

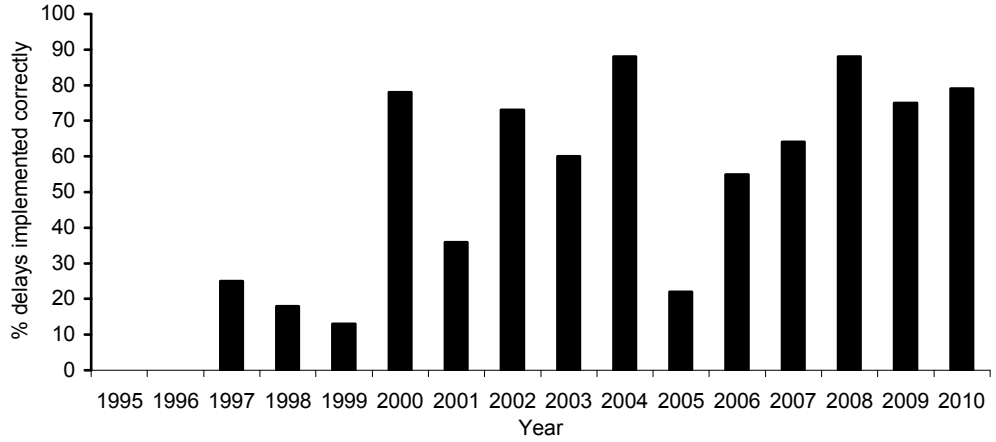

Figure 3.27. Proportion of occasions when delays due to the presence of marine mammals were implemented correctly within the UKCS (no delays were needed in 1995 or 1996).

There was an inverse relationship between the frequency with which a seismic contractor operates within the UKCS and the occurrence of poor practices on surveys (e.g. continued firing during long line changes). Those contractors conducting few surveys in 2009 and 2010 had a higher average proportion of surveys where there were poor practices (Figure

3.28). The same did not hold true for the clients commissioning the surveys, where the number of surveys made little difference to the occurrence of poor practices.

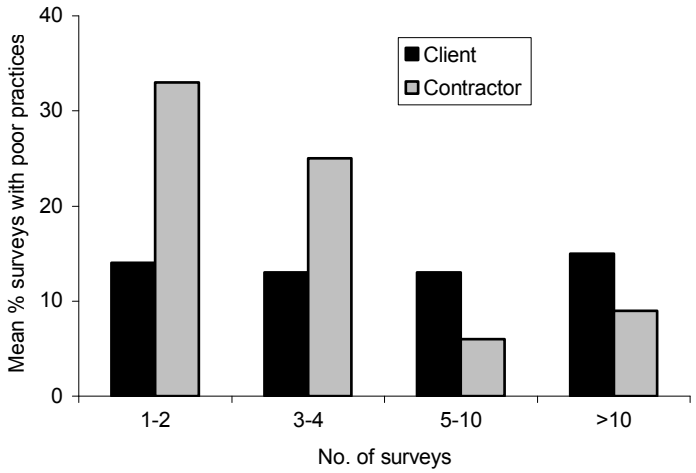

Figure 3.28. Proportion of surveys with poor practices in relation to number of surveys conducted by client or contractor within the UKCS in 2009 and 2010.

4 Discussion

Based on the results of this analysis, with particular attention to experiences noted by MMOs in their reports in recent years, a number of items are put forward for consideration when the JNCC guidelines are next reviewed. These items are purely in relation to the current version of the guidelines (JNCC 2010). The suggestions below do not represent JNCC's position on recommended revisions, but are items that may form the basis for further discussion and wider consultation during any review process. A list summarising these recommendations is included for reference in Appendix 3.

4.1 The pre-shooting search

The analysis only considered the duration of the pre-shooting search and did not examine how effective it was in terms of the MMO's ability to detect marine mammals during the search (testing detection abilities during the pre-shooting search would have been limited by small sample sizes due to the relatively short duration of the pre-shooting search; however, detection rates of MMOs and PAM operators were tested more widely and are considered in section 4.6). The majority of pre-shooting searches were of adequate duration, although this was not always the case on site surveys and VSP operations even though these survey types had fewer occasions when firing commenced following a period of silence. When a mini-airgun was used often there was no pre-shooting search, although the need for a pre-shooting search prior to firing a mini-airgun is included in the guidelines in the section on soft starts on site surveys (i.e. guidelines section 3.3.1). As such, it may be worth reinforcing this by also including it in the section on the pre-shooting search.

Standards of pre-shooting searches were lower where PAM was used at night compared to visual searches during daylight hours, perhaps reflecting the difficulties that were sometimes experienced in the deployment of the PAM array. The guidelines could emphasise that night-time pre-shooting searches using PAM should meet the same minimum duration as the visual search during daylight. The recommendation since June 2009 that PAM is used to supplement visual observations during daylight hours in areas of importance for marine mammals (i.e. guidelines section 5) was implemented infrequently. PAM may be useful during daylight pre-shooting searches for detecting submerged animals, particularly deep diving species such as sperm whales, or species that are difficult to detect visually, such as the harbour porpoise.

Good communication is the key to appropriate timing of the pre-shooting search. As most inadequate searches started too late, it might be helpful if the guidelines could stress the importance of the crew providing adequate advance warning of impending firing (at least 30 minutes in shallower waters and at least 60 minutes in waters deeper than 200m). To avoid occasions when the pre-shooting search ends prematurely, with the consequent risk that any marine mammals approaching close to the airguns when firing is imminent will be undetected, the guidelines could recommend that MMOs/ PAM operators continue searching until they have evidence (e.g. bubbles rising to the surface or airguns being audible) that the soft start has commenced.

Sometimes there was no pre-shooting search due to inadequate staffing levels. Operators, knowing the full details of their operations, should assess what staffing levels are sufficient for their requirements (e.g. number of line turns likely and as such number of MMOs/ PAM operators likely to be required to cover pre-shooting searches etc.) and engage further staff as necessary.

The guidelines could also require that the vessel operator ensures there are sufficient UHF radios to enable their use by MMOs and PAM operators to co-ordinate visual and acoustic detections and to ensure that if a marine mammal is detected in the mitigation zone during the pre-shooting search the relevant seismic personnel can be notified immediately.

4.2 Delays in firing

It is not surprising that most delays occurred on survey types with large airgun arrays, as these survey types typically have a long duration resulting in more occasions overall when airguns commenced firing. However, the increased proportion of occasions when a delay was required during VSP operations and prior to the first shots of other survey types in recent years might indicate an adaptive response. Typically the soft start commences from silence only once at the start of VSP operations (although there may be short gaps in firing periodically while geophones are repositioned). Any marine mammals encountered prior to these operations or prior to the first shots of other surveys would not have had recent exposure to airgun noise and may perhaps be in close proximity, whereas animals present after operations have commenced may be less likely to approach close and therefore less likely to cause a delay for subsequent uses of the airguns.

Although there has been some improvement in the proportion of delays that were correctly implemented over the years since the guidelines were first introduced, there needs to be further improvement. Often the soft start subsequent to a delay was too short; the guidelines could emphasise the need for a full soft start after any delay due to the presence of marine mammals to allow any undetected animals in close proximity time to move away before full power is reached. However, the most common failure with the requirement to delay was that the delay was not long enough. Instances where MMOs advised that firing could commence without waiting 20 minutes since the last detection of the animal within the mitigation zone are clearly in contravention of the guidelines. MMOs and PAM operators should be careful that any advice they provide aims to minimise the risk of injury or disturbance to marine mammals; allowing actions that are not in compliance with the guidelines reduces the protection afforded to marine mammals and creates inconsistency in the application of the guidelines.

Often there was apparently no attempt to delay firing; sometimes it seemed that MMOs were unaware that they were in a delay situation. It is unlikely that this was due to a lack of awareness of the requirements of the guidelines, as all MMOs working on the UKCS have to undergo MMO training where the requirements of the guidelines are fully explained. It is more likely that at the time of the sighting the MMOs were unaware of the impending firing. Although MMOs and PAM operators may be able to estimate the time when the soft start will commence by viewing onboard navigation screens, this is only approximate and accurate information is dependent on communication with the crew. Therefore it seems likely that poor communication may have been a factor in these cases. Although it is the responsibility of the MMO or PAM operator to ensure they are aware of planned operations on the vessel, it might be helpful if the guidelines were to recommend that MMOs or PAM operators are given advance warning of firing and are informed again immediately before the soft start commences.

4.3 The soft start

The 2004 guideline revision introducing alternative options for performing a soft start for site surveys and VSP operations (i.e. current guidelines section 3.3.1) led to a clear improvement in standards, with more soft starts of adequate duration and a dramatic

reduction in the number of occasions when there was no soft start. The alternative soft start methods (increasing the pressure or firing frequency) are intended for surveys where airgun array volumes are typically small. They should not be used for surveys with larger airgun volumes, particularly the increasing frequency method, where even the first shot uses the full array at full pressure and could pose a high risk of injury to marine mammals.

There are currently three specified durations in the guidelines (i.e. guidelines section 3.3) relating to the soft start: 1) from the start of the soft start to full power should be a minimum of 20 minutes; 2) from the start of the soft start to the start of line should not be significantly more than 20 minutes (more than 40 minutes would be considered excessive); and 3) the survey line should start immediately once full power is reached. It seemed that there were difficulties in complying with all three requirements together and MMOs have sometimes commented on this. On site surveys the duration of the soft start until full power was reached was too short more often than on other survey types. VSP operations often had an excessive period from the start of the soft start until the start of line, while on 2D, 3D and 4D surveys there was excessive firing at full power before the start of line.

The start of line is at a fixed location and although crews estimate the time of arrival at that location, the actual time of arrival may vary due to changes in the vessel's speed caused by factors such as tides and currents. It may therefore be difficult to judge when to begin the soft start such that all three criteria are met. The criterion least often met was that the survey line should start immediately once full power is reached. This requirement also does not allow for the noise files usually recorded before the start of each survey line, necessitating a brief pause in firing after full power is reached (usually for only a few minutes). For practical reasons therefore, the requirement to start the line immediately once full power is reached could be removed. Although unnecessary firing at full power before the start of line should continue to be discouraged, a maximum duration from the beginning of the soft start until the start of line would also achieve this. It is suggested that the criteria for the soft start are revised to: 1) the duration from the start of the soft start until full power should be a minimum of 20 minutes; and 2) the duration from the start of the soft start until the start of the survey line should be a maximum of 40 minutes.

Such criteria would allow some flexibility. Crews working in areas where tides or currents were proving problematical could aim to begin a soft start perhaps around 30 minutes before the estimated time of arrival at the start of line, then if the vessel's speed either increased or decreased they would still be likely to meet both the above criteria. Shots are usually based on distance over the ground rather than a time interval, so any increase or decrease in the vessel speed would result in a shorter or longer time to reach full power and would not necessarily increase significantly the time spent firing at full power before the start of line.

Although there was limited information, it seemed that firing during the soft start at volumes above production volume may be common on 2D, 3D and 4D surveys. It is suggested that the guidelines (and associated survey consent) prohibit any firing at volumes above production volume. If there is a need to fire the spare airguns during the soft start these could be fired at an appropriate point in the soft start and then swapped for airguns of similar volume, so that the spare airguns are not being fired in addition to the full array.

4.3.1 Unplanned breaks in operations

The current provision allowing firing to resume after an unplanned break of less than 10 minutes (providing a visual check confirms there are no marine mammals in the mitigation zone; i.e. guidelines section 3.3) is intended to mean that firing can resume at full power. Although it is usually interpreted as such, the wording could specify this more clearly. It should be emphasised that this provision is for unplanned breaks only (e.g. breakdown of

equipment) and should not be used for planned gaps in operations, or alternatively allow this provision also to apply to planned gaps of short duration (which would allow for recording of noise files). In either case, to prevent this provision being used as justification for prolonged intermittent firing during longer gaps in operations it should be stated that it should only be used where seismic data acquisition will continue within 10 minutes.

Although this provision in the guidelines appears to have been infrequently utilised, it is possible that this has been under-reported if such short breaks were not recorded on the 'Operations' form, instead just being regarded as continued firing. The relatively low number of occasions when there was no soft start suggests that where breaks have lasted for more than 10 minutes there has generally been compliance with the requirement for a soft start when recommencing firing.

4.3.2 Test firing

Although testing airguns creates additional noise input to the marine environment, the need for airgun tests cannot be removed. It might be advisable to incorporate airgun tests into the soft start whenever possible, to reduce overall noise input to the environment. However, it needs to be recognised that for various reasons this will not always be possible e.g. when testing individual airguns in succession one at a time, or if it is anticipated that problems may take some time to fix necessitating testing further in advance of the start of line. The current wording in the guidelines regarding airgun testing needs to be amended (i.e. guidelines section 3.3.2). The guidelines refer to low and high power firing of a single airgun; an airgun is either firing or not, so the reference to low and high power in this context should be removed. Instead this section should just refer to a single airgun, the full array or a number of airguns but not the full array.

4.4 Line change

The criteria for being able to continue firing during line changes appear satisfactory for surveys with airgun volumes of 180 cu. in. or less, where firing is allowed to continue if the line change is expected to be less than 40 minutes (i.e. guidelines section 3.4.2). Most line changes when firing continued on these surveys were within the 40 minute threshold, with very few exceeding 50 minutes. Whilst there will always be a need to allow some flexibility due to unexpected decreases in vessel speed resulting in a longer line change, it seems reasonable to continue with the 40 minute threshold for surveys with low volumes of airguns.

The option to continue firing during short line changes on surveys with airgun volumes of 500 cu. in. or more should be clearly specified in the guidelines (currently it is only implied). An appropriate shot point interval during the continued firing could be specified, which for consistency with the measures for smaller airgun volumes could be an increased shot point interval but ideally not more than five minutes. Currently the expected line change duration above which firing of large volume airgun arrays must stop is 20 minutes (i.e. guidelines section 3.4.1). On OBC surveys many line changes were around 20 minutes duration, leading to difficulties in decision making. Where crews on surveys with large airgun arrays (mostly OBC surveys) decided to continue firing, almost a third of line changes exceeded 20 minutes, but most were completed within 30 minutes. It is therefore suggested that the line change duration within which firing may continue on surveys with airgun volumes of 500 cu. in. or more is increased to 30 minutes. Balanced against the need to set thresholds that are achievable is the need to minimise acoustic input to the environment by setting the threshold as low as is practically possible.

Where line changes are sufficiently short to allow firing to continue during the turn, the guidelines currently do not specify the volume. Reducing the volume reduces the level of noise, but risks a relatively steep increase back to production levels at the end of the turn. Remaining at full volume avoids the need for a steep increase, but noise levels are greater throughout the turn. There may be a case for a different approach on different types of surveys, depending on the total airgun volume and the level of noise. If volume were to be specified this should be considered in consultation with industry regarding what is feasible.

The guidelines do not specify what to do during line changes with airgun volumes between 180 cu. in. and 500 cu. in., but these surveys are quite rare. Where situations arise that are not specifically covered in the guidelines consultation with DECC and JNCC is considered good practice, particularly where these situations may be anticipated well in advance.

It would also be worth clarifying in the guidelines that the use of a 'mitigation gun' during long line changes is not permitted at any time within the UKCS. Some other jurisdictions permit the firing of a single small volume airgun during line changes of any duration and occasionally this practice has been conducted within the UKCS (or crews have planned to use a 'mitigation gun' but the MMOs have advised against it). Some species are displaced when airguns are firing, in the case of sperm whales and harbour porpoises even with smaller airgun arrays (Stone 2015). The aversive responses observed in a harbour porpoise by Lucke *et al* (2009) followed exposure to sound from a single 20 cu. in. airgun. Allowing continued firing of a small volume airgun during long line changes could lead to continuous airgun sound for a period of days or even weeks on a survey, and could potentially result in a sustained impact on sensitive species such as the harbour porpoise. It would be helpful to MMOs providing advice on this matter if the guidelines clearly specified that the use of a 'mitigation gun' during long line changes is not an acceptable practice in the UKCS.

4.4.1 VSP operations

On VSP operations there was confusion as to what to do during gaps in firing when repositioning the geophones in the well. Many operators took the reference in the guidelines to unplanned breaks in firing of less than 10 minutes (where if no marine mammals have been detected within 500m of the airgun array firing can re-commence; i.e. guidelines section 3.3) as a guide, without consultation with DECC or JNCC. They interpreted this as allowing them to continue without another soft start providing they fired shots at least every nine minutes, but this provision in the guidelines is intended for unplanned short breaks in firing only. It is not intended for planned breaks (such as for repositioning geophones on a VSP operation), nor is it intended to allow intermittent firing during breaks that in total exceed 10 minutes.

Procedures specific to VSP operations should be considered in the guidelines, as these operations are common within the UKCS. One option would be to allow a short silent period within which firing could recommence at full power (providing a watch had been kept during the silent period and no marine mammals were detected in the mitigation zone). As with the provision for unplanned breaks in firing, operations might be allowed to resume at full power for gaps in acquisition of less than 10 minutes. Longer gaps would require a full pre-shooting search and soft start to recommence, as there is a greater chance that any animals deterred by the noise of the airguns may return to the vicinity during a longer silent period. This would also aid reducing overall noise input to the marine environment, by prohibiting intermittent firing during longer gaps in acquisition.

Alternatively, firing could be allowed to continue during gaps in acquisition up to a specified maximum duration, with longer gaps requiring the airguns to be stopped, similar to the approach currently used during line changes. As with line changes on surveys with small

airgun volumes, firing should stop and a pre-shooting search and soft start be performed for gaps in acquisition expected to exceed 40 minutes; for shorter gaps firing could continue at an increased shot point interval, ideally no more than five minutes. There would need to be guidance regarding whether the full array or a single airgun should be fired.

There is insufficient data in the database to assess what is a typical duration of a gap in acquisition during VSP operations to allow relocation of the equipment within the well, so the feasibility of these measures should be established in consultation with companies that specialise in VSP operations. Allowing a short silent period will only be useful if gaps in acquisition are typically within the specified duration (perhaps 10 minutes). Continued firing might be more appropriate if gaps are typically longer, but would only be feasible where the duration of any gap is able to be predicted with reasonable accuracy, so that the decision to continue firing or to stop could be made with confidence. There may be a case for allowing either approach depending on the circumstances.

4.5 Passive acoustic monitoring

4.5.1 Use of PAM on surveys

Acoustic monitoring and visual monitoring each have limitations. Animals will only be detected acoustically if they are vocalising (and for species that make directional vocalisations, if they are vocalising towards the hydrophone). Any individual animal may be silent at any given time and would not be detected using PAM. However, animals will only be detected visually when they are at the water surface and some conditions (darkness, poor weather) make visual detections difficult or impossible. Advice provided to operators over the years has increasingly recommended the use of PAM in addition to visual monitoring, particularly in areas considered important for marine mammals, such as west of Shetland, the Moray Firth and Cardigan Bay. As PAM has become more available and has been included in consent conditions more, its use has steadily increased.

There were practical issues specific to PAM that merit consideration regarding whether these would be best addressed in the seismic guidelines or in specific PAM guidelines. Where there are difficulties with PAM deployment there could be a requirement to extend the line turn sufficiently to allow a full pre-shooting search with PAM. Furthermore, there could be a recommendation to focus attention on providing appropriate sites for deployment of PAM equipment on vessels that would minimise the need to recover the PAM array (whilst still being positioned close to the source), thereby minimising the need to extend line turns. Industry needs to take the lead on this; further development and refinement of PAM arrays incorporated into the seismic streamers would be worthwhile as this eliminates both the need to recover the PAM array during turns and also the risk of entanglement in poor weather conditions, which sometimes led to PAM not being used. Improved deployment should lead to an improved standard of pre-shooting searches using PAM, which tended to meet the minimum required duration less often than visual pre-shooting searches (section 3.2).

4.5.2 Use of PAM for operations commencing at night

PAM was particularly beneficial at night when visual monitoring was not possible. In such conditions PAM offers a means of detecting at least some marine mammals that would otherwise be undetected. It is apparent that visual observations at dusk cannot be used as a predictor of the presence of cetaceans at night to inform decisions on commencing operations at night without PAM, so there is a need for PAM during hours of darkness.

Although the use of PAM has increased, there were more occasions overall when the airguns commenced firing at night without PAM than with PAM. PAM was used more at night in areas where its use was likely to be stipulated during the consent process, such as west of Shetland, but less so in some other areas. Whilst the use of PAM may not be a consent condition for all surveys, nevertheless it is up to the operator to decide, knowing the detail of their operations, whether they are likely to need PAM to avoid breaching the guidelines, or alternatively to plan their operations to minimise the risk to marine mammals if they choose not to use PAM (e.g. by limiting commencing operations to daylight hours). On site surveys and VSP operations, where there are fewer occasions when the airguns commence firing after a period of silence, more effort could be made to commence firing during daylight hours if PAM is not available. The guidelines currently recommend such planning on site surveys and VSP operations (i.e. guidelines section 3.3.1), but only "whenever possible". Although site surveys use lower volumes of airguns that may pose a lower risk of injury to marine mammals, nevertheless there were many occasions when firing on site surveys commenced at night with no means of detecting marine mammals.

Currently the recommendation to use PAM prior to firing during hours of darkness or low visibility or increased sea states is prefaced in the guidelines by a statement that, "The operator should whenever possible implement the following best practice measures" (i.e. guidelines section 1.1). Clearer guidance is needed on when PAM is required in order to start firing at night or in poor weather, as use of phrases such as "whenever possible" leaves it open to interpretation and from some MMO reports it was evident that there was uncertainty about whether PAM was required. As these best practice recommendations were often not adopted there may be a need to strengthen them and this might include not allowing firing to commence during hours of darkness unless effective monitoring can be achieved by alternate means.

4.5.3 Use of PAM for operations commencing in poor weather

The best practice recommendation to use PAM prior to firing during low visibility or increased sea states (i.e. guidelines section 1.1) was not consistently adopted. As with night-time operations, there may be a need to strengthen the best practice recommendations. This might include not allowing firing to commence during weather conditions not conducive to visual detection of marine mammals unless alternative methods are used to supplement (but not substitute) visual monitoring, particularly for surveys in areas of importance for marine mammals. Further specification of weather conditions when firing could not commence with visual observations alone, e.g. actual sea states, may need to be considered to aid in decision making on board.

Ideally the commencement of firing would be limited to optimal weather conditions for detecting marine mammals, but this may have substantial cost implications for the industry. Applying restrictions only to very poor weather conditions ('rough' sea state or 'large' swell or 'poor' visibility as defined on the 'Effort' form) would have a relatively small impact. Poor visibility was the most frequent limiting weather condition recorded; PAM can be effectively used in poor visibility so its use would reduce the impact of restrictions on starting in very poor conditions. For conditions of increased sea state or swell there should also be consideration of whether an effective search can be made acoustically; there may need to be some limit beyond which firing should not commence at all as an effective search cannot be made by any means. Such limitations would be most likely to be restrictive for OBC surveys, which can continue in fairly rough weather conditions as the streamers are laid on the seabed, protected from the effects of swell. However, OBC surveys have short line changes, and if the guidelines permitted firing to continue for line changes within an appropriate duration there would be fewer occasions when firing would commence from

silence, reducing the impact of not being allowed to start in poor weather. MMOs have sometimes commented in their reports that lines shot in marginal weather conditions are often not of acceptable quality and are re-shot, creating unnecessary additional noise. Not allowing firing to commence in conditions where an effective pre-shooting search is not possible by any means would have the added benefit of preventing some of this unnecessary noise production.

4.5.4 Detection rates using PAM compared to visual sighting rates

Species identification was difficult with PAM, although it is not necessary for the implementation of the JNCC guidelines. The lower acoustic detection rates (compared to visual) for some species or species groups and the almost complete lack of detection of baleen whales confirm that PAM should complement rather than be a substitute for visual observations at times when visual monitoring is possible. Potter *et al* (2007) also had more visual than acoustic detections of marine mammals per hour during a seismic survey.

For animals in the mitigation zone, the reduction in acoustic detection rates (compared to visual) was evident for all species or species groups tested. The difficulty of estimating the range of acoustic detections may partially account for this result, as only those detections where range was estimated would have been included in the analysis. However, significant reductions for some species regardless of range suggest that there may have been other factors involved. These results confirm that PAM should not be relied on as a sole monitoring method for mitigation purposes when visual monitoring is possible.

4.5.5 Range estimation using PAM

PAM technology needs to improve with regard to range estimation, both the ability to provide an estimate of range and the accuracy of that estimate. Until such time there should be consideration as to whether delays should be required for all acoustic detections of marine mammals unless there is confirmation that the animal is outside the mitigation zone, either by an acoustic estimate of the range or by visual confirmation of the range (i.e. if there is no estimate of range by any means assume the animal may be in the mitigation zone and delay the commencement of firing). The cost of this would probably be low; in 2010 there would have been just two additional delays had this been a requirement, although delays may become more frequent if PAM is used more widely according to best practice.

4.5.6 Delays in firing when using PAM

There were some delays in seismic operations at night due to acoustic detections of marine mammals; with visual monitoring alone these animals would have been undetected and firing would have commenced while they were in the mitigation zone. Although delays were more often correctly implemented following an acoustic detection of marine mammals in the mitigation zone, it should be noted that occasions when delays were required but not properly implemented were readily apparent from the data for visual observations as distance from the airguns was usually recorded, whereas this was not the case for acoustic monitoring.

4.6 MMOs and PAM operators

4.6.1 Dedicated observers, non-dedicated observers and PAM operators

Although there was compliance with the recommendation to have two MMOs on surveys north of 57^{o} latitude between 1st April and 1st October (i.e. guidelines section 5), long daylight hours also occurred during this period south of this latitude, occasionally resulting in absent pre-shooting searches if only one MMO was used. The guidelines could specify that two MMOs should be provided on all surveys between 1st April and 1st October, regardless of latitude. There is currently no equivalent requirement regarding the number of PAM operators, so the guidelines could specify that there should be adequate numbers of PAM operators (e.g. two should be used if hours of darkness are long or if PAM is to be used in daylight hours as well). Having a single MMO doubling-up as a PAM operator is only practical where both monitoring methods are not running concurrently and should only be an option where there are very few occasions when the airguns commence firing (e.g. on VSP operations), as even if PAM is only being used at night doubling-up still requires 24 hour availability (although not constant coverage) by one person.

The risk of injury to marine mammals may be less on site surveys and VSP operations, so dedicated MMOs are often not required. However, use of dedicated MMOs led to increased detections of marine mammals and better implementation of the guidelines, so it is suggested that there could be wider use of dedicated personnel. Communication is an important part of any MMO role and occasions when delay procedures were not correctly implemented occurred for all types of MMOs, although less so for dedicated MMOs. The importance of good communication needs to be emphasised for all types of personnel, whether dedicated or not.

4.6.2 Benefits of relevant prior experience

The guidelines encourage the use of experienced and dedicated MMOs, particularly in areas of importance for marine mammals (i.e. guidelines section 5). However, the guidelines could encourage operators, whenever they plan to use dedicated MMOs on their surveys, to seek to engage appropriately experienced personnel, as those with relevant marine mammal experience prior to becoming a dedicated MMO had better detection abilities than those without. Good detection abilities are an essential part of the role of the MMO, enabling marine mammals in the mitigation zone to be detected and delays in firing implemented accordingly. Therefore there are clear benefits to having appropriately experienced personnel.

4.7 Other items for consideration

References to a mini-airgun in the guidelines should be amended to clarify that this is an airgun of volume less than or equal to 10 cu. in. (instead of less than 10 cu. in. as is currently stated; i.e. guidelines sections 3.3. and 3.3.1).

There could perhaps be a separate section in the guidelines addressing the particular issues that arise during OBC surveys, such as short line turns and whether it is acceptable for firing to commence in weather conditions when an effective pre-shooting search is not possible.

Given the increased tendency for poor practices on surveys conducted by seismic contractors who undertook seismic surveys within the UKCS infrequently (section 3.8.3), it would be worth ensuring that any such contractors fully understand the requirements of the

guidelines before a survey commences. The guidelines (and associated survey consent) could note that it is the operator's responsibility to ensure that all contractors are aware of, understand and comply with the requirements therein.

There were a few occasions when a deviation from the procedures outlined in the guidelines was agreed in advance with DECC and JNCC. However, often when crews were not clear about how best to proceed (e.g. on VSP operations) there was no consultation with DECC or JNCC. The guidelines could encourage more consultation with DECC and JNCC before and during surveys, where there are operations that are not fully addressed in the guidelines. The guidelines could also recommend that any agreed deviations from the standard procedures should be fully documented (e.g. with copies of e-mails) in the MMO report, so that such deviations are not treated as a non-compliance when examining the data. Similarly, it would be helpful if a copy of the consent was included in the MMO report, so any particular conditions for that survey are apparent to anyone examining the report. Although the guidelines note that the MMO can request a copy of the consent, the onus should perhaps be on the operator to provide this as the MMO needs to be aware of any relevant conditions that apply.

Some instances of non-compliance recorded in the data forms are not immediately obvious without detailed examination of the data, although many MMO reports will refer to such instances. Further development of a standard way of highlighting instances of non-compliance and reporting such instances to DECC in a timely manner should be considered.

4.8 MMO and PAM training

Some areas where compliance with the guidelines could be improved could be specifically addressed during training courses. MMOs could be made aware of a number of 'common pitfalls' with the aim of improving standards in these areas. Although all the requirements of the guidelines are covered in existing training courses, highlighting areas where standards are currently lower than is desirable may focus MMOs' attention on improving standards in these specific areas. For example, training courses already provide instruction on what the minimum duration of the pre-shooting search should be, but mentioning that pre-shooting searches more often fail to meet the minimum duration on site surveys and VSP operations than on other survey types may encourage new MMOs to ensure that pre-shooting searches are long enough on all surveys. Some areas for improvement (e.g. standards of pre-shooting searches) are within the direct control of the MMO, so addressing these during training has the potential to result in significant improvements.

Other areas for improvement (e.g. standards of soft starts) are not under the direct control of MMOs, but addressing them in training may encourage MMOs to be alert to lapses in standards and to provide advice to crews where appropriate. Based on the analysis presented in this report, training course providers could be issued with a list of items to highlight during courses, representing areas where improvements in standards are sought. This would only capture newly trained MMOs, so there is perhaps need for a refresher course or some other means of reaching previously trained MMOs. Any refresher course offered should, in addition to highlighting areas for improvements, summarise requirements of current guidelines and recording forms and identify key changes from previous versions.

PAM operators should also receive MMO training, to ensure that they are aware of and understand the mitigation measures contained within the JNCC guidelines. Additional PAM training, as well as providing training in available software, should also attempt to address issues relating to PAM, including those regarding the duration of the pre-shooting search. Such issues are often connected with deployment of PAM, with pre-shooting searches being

compromised where deployment is difficult. Selecting effective deployment options should therefore form part of any PAM course. The ability to estimate range is of critical importance in the implementation of the guidelines but has proved difficult with PAM, so PAM training courses should address both how to estimate range and the limitations of the equipment in being able to do so. Other issues that should be addressed during PAM training include interference from background noise, setting up the equipment (including selecting effective deployment options and reducing interference from background noise) and classification of vocalisations. Troubleshooting (likely problems and their solutions) should also be incorporated into any PAM course. The development of specific PAM guidelines or a PAM section within the current guidelines should also be considered to help address some of the above issues.

As well as the need for MMOs and PAM operators to attend relevant training courses, there also needs to be recognition of the value of experience. Detection (visual or acoustic) of marine mammals is a key component in the implementation of the guidelines, but is a skill that takes many months to develop. There should not be an expectation that someone with no experience of marine mammals could, on the basis of a training course alone, be as skilled at detecting and identifying marine mammals as someone with experience. While training equips MMOs with knowledge specific to the guidelines, it should be considered together with experience by industry representatives when assessing someone's suitability as an MMO or PAM operator for their specific programme of work. This is particularly so for PAM, where the technical nature of the subject demands a certain level of expertise that only comes with repeated experience.

5 Conclusions

This analysis of MMO data has resulted in a number of suggestions for consideration when the guidelines are next revised. These suggestions include: improved communication between seismic crews and MMOs/ PAM operators; additional guidance on the use of PAM; strengthening the existing best practice recommendations; consideration of restricting commencement of firing in weather conditions when an effective pre-shooting search cannot be made either visually or acoustically; clarifying the criteria for soft starts; revising criteria for line changes on surveys with large airgun arrays; restricting excess noise due to exceeding production volume; including new sections for VSP operations and OBC surveys to address specific issues encountered on these operations; adequate staffing; encouraging operators to use appropriately experienced personnel; and further clarification of existing mitigation measures, as well as suggestions for further elements of training for both MMOs and PAM operators.

MMO data provides a valuable resource for evaluating the mitigation measures within the guidelines and this report represents one of the longest term analyses of MMO data to date. There is a need to continue to collect MMO data in order to test the effectiveness of the guidelines and compliance therewith. Such studies should aim to improve mutual understanding between regulators/ advisors and industry in order that mitigation is applied correctly, is logistically feasible, is well justified and is proportional to the risk to species.

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Appendix 1

Supplementary information

Table 8.1 Division of cetacean species into combined species groups for analysis (combined species groups also included unidentified animals within that group).

Baleen whales	Beaked whales	Delphinids	Small odontocetes
Northern right whale	Northern bottlenose whale	Long-finned pilot whale	Risso's dolphin
Humpback whale	Sowerby's beaked whale	Killer whale	Bottlenose dolphin
Blue whale		False killer whale	White-beaked dolphin
Fin whale		Risso's dolphin	Atlantic white-sided dolphin
Sei whale		Bottlenose dolphin	Short-beaked common dolphin
Minke whale		White-beaked dolphin	Striped dolphin
		Atlantic white-sided dolphin	Harbour porpoise
		Short-beaked common dolphin	
		Striped dolphin	

Table 8.2 Species of marine mammal encountered during seismic surveys within the UKCS from 1995-2010.

Species	No. sightings/ acoustic detections	No. individuals
Seal sp.	91	121
Grey seal	108	113
Harbour seal	23	24
Cetacean sp.	499	3,303
Whale sp.	277	514
Large whale sp.	180	380
Northern right whale (probable)	1	1
Humpback whale	21	47
Blue whale	12	13
Fin whale	332	765
Sei whale	20	27
Humpback/ sperm whale	20	25
Blue/ fin/ sei whale	17	28
Fin/ sei whale	124	247
Fin/ sei/ humpback whale	51	105
Fin/ sei/ blue/ humpback whale	162	357
Fin/ blue whale	38	78
Sperm whale	508	705
Medium whale sp.	79	129
Minke whale	702	825
Beaked whale sp.	9	21
Northern bottlenose whale	10	44
Minke/ northern bottlenose whale	1	1
Sowerby's beaked whale	6	14
Long-finned pilot whale	422	8,384
Killer whale	327	2,192
Long-finned pilot/ false killer whale	1	1
False killer whale/ killer whale/ Risso's dolphin	1	2
Delphinid sp. (dolphin, long-finned pilot, killer, false killer whale)	9	9
Dolphin sp.	1,508	18,330
Dolphin sp. (not porpoise)	65	550
Unpatterned dolphin (Risso's/ bottlenose)	5	28
Risso's dolphin	76	671
Bottlenose dolphin	90	1,095
Patterned dolphin (common/ striped/ white-beaked/ Atlantic white-sided)	104	2,280
White-beaked dolphin	1,159	16,096
Atlantic white-sided dolphin	701	43,491
Lagenorhynchus sp.	168	5,524
Short-beaked common dolphin	127	3,708
Striped dolphin	7	380
Short-beaked common/ striped dolphin	3	25
Short-beaked common/ striped/ Atlantic white-sided dolphin	1	4
Short-beaked common/ Atlantic white-sided dolphin	18	262
Harbour porpoise	523	1,083
Total	**8,452***	**112,002**

*includes some mixed species sightings

Appendix 2

Scientific names of species mentioned in the text

Harbour seal	*Phoca vitulina*
Grey seal	*Halichoerus grypus*
Northern right whale	*Eubalaena glacialis*
Humpback whale	*Megaptera novaeangliae*
Blue whale	*Balaenoptera musculus*
Fin whale	*Balaenoptera physalus*
Sei whale	*Balaenoptera borealis*
Minke whale	*Balaenoptera acutorostrata*
Sperm whale	*Physeter macrocephalus*
Northern bottlenose whale	*Hyperoodon ampullatus*
Sowerby's beaked whale	*Mesoplodon bidens*
Long-finned pilot whale	*Globicephala melas*
Killer whale	*Orcinus orca*
False killer whale	*Pseudorca crassidens*
Risso's dolphin	*Grampus griseus*
Bottlenose dolphin	*Tursiops truncatus*
White-beaked dolphin	*Lagenorhynchus albirostris*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Short-beaked common dolphin	*Delphinus delphis*
Striped dolphin	*Stenella coeruleoalba*
Harbour porpoise	*Phocoena phocoena*

Appendix 3

Summary of considerations for revisions to JNCC guidelines

Below is a list summarising items for consideration when the JNCC guidelines are next revised, based on the analysis presented in this report. For a full discussion of these suggestions refer to section 4. The suggestions below do not represent JNCC's position on recommended revisions, but are items that may form the basis for further discussion and wider consultation during any review process.

Suggested revisions:

The pre-shooting search

- emphasise that the pre-shooting search applies to the use of airguns of any volume, including a mini-airgun;
- emphasise that night-time pre-shooting searches using PAM should meet the same minimum duration as the visual search during daylight;
- note the importance of the crew providing adequate advance warning of impending firing;
- recommend that MMOs/ PAM operators continue searching until they have evidence (e.g. bubbles rising to the surface or airguns being audible) that the soft start has commenced;
- recommend that the vessel operator should provide sufficient UHF radios for MMOs and PAM operators to use.

Delays in firing

- emphasise that a full soft start must be done after any delay due to the presence of marine mammals;
- in addition to advance warning crews should inform MMOs or PAM operators again immediately before the soft start commences;
- stress the importance of good communication.

The soft start

- the requirement to start the line immediately once full power is reached should be removed and the criteria for the soft start revised to: 1) the duration from the start of the soft start until full power should be a minimum of 20 minutes; and 2) the duration from the start of the soft start until the start of the survey line should be a maximum of 40 minutes;
- prohibit any firing at volumes above the production volume.

Unplanned breaks in operations

- clarify that firing can resume at full power after a break of less than 10 minutes (provided there are no marine mammals in the mitigation zone);
- emphasise that the provision to allow firing to resume at full power after a break of less than 10 minutes (provided there are no marine mammals in the mitigation zone) is for unplanned breaks only, or allow this also to apply to planned gaps in operations;
- specify that the provision to allow firing to resume at full power after a break of less than 10 minutes (provided there are no marine mammals in the mitigation zone) should only be used where seismic data acquisition will continue within 10 minutes.

Test firing

- recommend that airgun tests are incorporated into the soft start whenever possible;

- procedures for testing should refer to a single airgun, the full array or a number of airguns but not the full array and should remove reference to a single airgun being fired at low or high power.

Line changes

- clarify that firing can continue during short line changes on surveys with airgun volumes of 500 cu. in. or more;
- where firing continues during short line changes on surveys with airgun volumes of 500 cu. in. or more the shot point interval should be increased (but ideally not more than five minutes);
- the line change duration within which firing may continue on surveys with airgun volumes of 500 cu. in. or more should be increased to 30 minutes;
- where line changes are sufficiently short to allow firing to continue during the turn, the guidelines could specify the volume (reduced or full power, possibly with a different approach depending on total airgun volume and the level of noise);
- specify that the use of a 'mitigation gun' during long line changes is not an acceptable practice in the UKCS.

VSP operations

- procedures specific to VSP operations should be considered;
- either allow firing to resume at full power for gaps in acquisition of less than 10 minutes (providing a watch during the gap confirms there are no marine mammals in the mitigation zone) with longer gaps requiring a full pre-shooting search and soft start before recommencing (intermittent firing being prohibited);
- alternatively, allow firing to continue at an increased shot point interval (not more than five minutes) for gaps in acquisition not expected to exceed 40 minutes with longer gaps requiring firing to stop and a full pre-shooting search and soft start before recommencing.

Use of PAM

- the development of specific PAM guidelines or a PAM section within the current guidelines should be considered;
- if there are difficulties with PAM deployment the line turn should be extended sufficiently to allow a full pre-shooting search with PAM;
- appropriate sites should be provided for deployment of PAM equipment close to the source with minimal need for recovery;
- strengthen the requirement that operators should plan to avoid commencing firing during hours of darkness on site surveys and VSP operations if PAM is not available;
- for clarity, avoid use of phrases such as "whenever possible";
- strengthen best practice recommendations by not allowing firing to commence during hours of darkness unless effective monitoring can be achieved by alternate means, (visual observations at dusk cannot be used as a predictor of the presence of cetaceans at night to inform decisions on commencing operations during hours of darkness);
- strengthen best practice recommendations by not allowing firing to commence during weather conditions not conducive to visual detection of marine mammals unless alternative methods are used to supplement (but not substitute) visual monitoring, particularly for surveys in areas of importance for marine mammals;
- specify weather conditions when firing could not commence with visual observations alone;
- specify limits of sea state and swell beyond which firing should not commence at all as an effective search cannot be made by any means;
- PAM should not be relied on as a sole monitoring method for mitigation purposes when visual monitoring is possible;

- delays should be required for all acoustic detections of marine mammals unless there is confirmation that the animal is outside the mitigation zone, either by an acoustic estimate of the range or by visual confirmation of the range.

MMOs and PAM operators

- two MMOs should be used for all surveys between 1st April and 1st October;
- two PAM operators should be used where PAM is to be available during the day and night or when hours of darkness are prolonged;
- a single person should only double-up as MMO and PAM operator where visual and acoustic monitoring are not running concurrently and there are very few occasions when the airguns commence firing;
- recommend wider use of dedicated MMOs;
- encourage use of dedicated MMOs with prior marine mammal experience.

Other items for consideration

- the definition of a mini-airgun should be amended to an airgun of volume less than or equal to 10 cu. in.;
- add a separate section for OBC surveys addressing issues such as short line changes and commencing firing during poor weather conditions;
- state that it is the operator's responsibility to ensure that all seismic contractors are aware of, understand and comply with the requirements of the guidelines;
- the operator should be required to provide the MMOs and PAM operators with a copy of the consent;
- a copy of the consent for the survey should be included in the MMO report;
- encourage consultation with DECC and JNCC where situations arise that are not specifically covered in the guidelines, with documentation of any agreed deviation from standard procedures (e.g. copies of e-mails) to be included in the MMO report;
- further development of a standard way of highlighting instances of non-compliance and reporting this to DECC in a timely manner.

Training elements

- based on the results of this analysis, MMO course providers could be given a list of items to highlight during courses representing areas where improvements in standards are sought;
- consider development of MMO refresher courses;
- consider development of PAM courses;
- recognition of the value of experience in addition to training.