Marine mammal observations and compliance with JNCC guidelines during explosives operations from 2010-2021.

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Summary

This project analysed data from projects using explosives in UK waters between 2010 and 2021 to assess:

1. Compliance with JNCC guidelines for the use of explosives and with licence conditions (where these were available for examination) and
2. To assess the response of marine mammals to explosives. Explosives are used in UK waters primarily for oil and gas (O&G) decommissioning and for clearance of unexploded ordnance (UXO).

No MMO report or data were submitted for over half of the known O&G decommissioning projects and for almost a third of UXO clearance projects. Some data were provided in formats other than the required Excel spreadsheets; for a few projects the data were not of sufficient quality and had to be discarded. Where data were usable, corrections were still required prior to inclusion in the database. Following quality checks, data from 32 projects were examined.

Over 1,600 hours were recorded as monitoring for marine mammals (over 1,200 hours visual monitoring and over 400 hours acoustic monitoring), with 46% of the time spent monitoring being prior to the first detonation of a project. Acoustic deterrent devices were active for 8% of the monitoring time and scare charges were being used for 3% of the monitoring time.

A total of 90 marine mammal visual sightings and two acoustic detections were reported, comprising 211 individual animals. Of the two acoustic detections, one was first detected visually. The most frequently encountered identified species was the minke whale, followed by the grey seal and the harbour porpoise. The distribution of encounters largely reflected survey effort and known species distribution.

UXO clearance projects used two or more dedicated MMOs slightly more often than decommissioning projects, but most projects had one dedicated MMO. PAM was used more often on UXO clearance projects than decommissioning projects. All projects where the licence required acoustic monitoring used PAM except for one UXO clearance project. Where PAM was used, in all cases there was only one PAM operator. On some UXO projects, a single person was used as a dual role MMO / PAM operator. There were no cases where a single person undertook a dual role on decommissioning projects, although PAM was used less often on these projects.

During the period 2010–2021, there was full compliance with the requirements for visual pre-detonation searches in daylight on decommissioning projects (although two detonations took place at night with no visual search) and most searches on UXO clearance projects (94%) were also compliant. However, there were concerns about the effectiveness of the search, due to the position of the main vessel at a stand-off distance and due to smaller vessels having a low height of eye. On projects where PAM was available (but not a license condition), acoustic searches in daylight were often inadequate, both on decommissioning and UXO projects, usually because the search was not of the recommended duration. Where the licence required PAM to be used, acoustic searches prior to UXO clearance were usually of adequate duration (72%), but less were of adequate duration for decommissioning (52%).

Acoustic deterrent devices (ADDs) were used before 84% of detonations, more often on UXO clearance projects than decommissioning projects. ADDs were almost always used on projects where they were required as a condition of the licence, although where durations

were specified, these were often exceeded. ADDs were usually switched off prior to detonations / scare charges, although mostly not more than five minutes beforehand.

There were three occasions when detonations were required to be delayed due to the presence of marine mammals within the mitigation zone, in two cases for grey seals on UXO clearance projects and in the other case for long-finned pilot whales on a decommissioning project. On all three occasions, detonations were delayed for at least 20 minutes after the last sighting in the mitigation zone. However, ADDs were used throughout two of the delays to deter the seals.

Scare charges were only used on UXO clearance projects, where they were used before 50% of detonations. The duration of scare charge use increased with the number of scare charges employed; three charges was the most common number used. Usually, the main detonation was immediately after the last scare charge, but on some occasions, there was a gap between the scare charges and the detonation. For the main detonations there was no evidence that detonations were ordered to give a progressive increase in charge size throughout projects.

Noise abatement was not common. Bubble curtains were used on only two UXO clearance projects where they were required by the licence. Another UXO clearance project used a low-noise alternative method rather than a high-order detonation.

Detonations mostly took place in daylight and good visibility, as recommended to enable a visual search beforehand. There were two detonations at night on a decommissioning project and one detonation at dawn and one at dusk on UXO clearance projects. PAM was used at night, and visual or a mix of visual and acoustic monitoring was used at dawn or dusk. There were no detonations in poor visibility, but a small number of detonations in moderate visibility where potentially the ability to observe the full extent of the mitigation zone may have been compromised, although PAM was used to supplement visual monitoring on most of these occasions. However, 25% of detonations commenced in poor or suboptimal sea conditions; PAM was used to supplement visual monitoring in most cases.

An adequate duration post-detonation search was conducted more often on UXO projects than decommissioning projects. Approximately one-fifth of post-detonation searches on decommissioning projects were inadequate. Where impacts were noted, the most common was dead fish floating at the surface. Feeding birds were sometimes seen, usually in combination with dead fish. There were two occasions where dead crabs were seen and one occasion when dead birds (two guillemots) were observed.

The low number of sightings / acoustic detections limited the ability to examine the response of marine mammals to explosives, particularly for individual species. Where data could be analysed, sample sizes were low, so the results should be treated with caution. No significant differences were found in detection rates of seals or cetaceans between periods prior to and post detonations. Similarly, there were no significant differences in detection rates of grey seals or the combined groups of all seals or all cetaceans between the hours following detonations on the detonation date and all other periods. Seals were not significantly further from the detonation site in the hours following detonations compared to other times.

There were insufficient data to assess the effectiveness of ADDs or scare charges. One grey seal appeared in the mitigation zone while an ADD was active; although it was recorded as swimming away from the vessel it resurfaced in the mitigation zone after 20 minutes of further ADD use. Another grey seal appeared in the mitigation zone just after the last in a sequence of scare charges. There were no other detections during ADD or scare charge use.

Recommendations are made for items to be considered when the explosives guidelines are next revised. These include: a greater emphasis on noise abatement (e.g. bubble curtains, low-order UXO clearance methods); ensuring there are sufficient numbers of mitigation personnel; consideration of the need for two observation platforms and/or PAM arrays; strengthening the requirement to commence detonations in daylight and good visibility, with more specific criteria including ensuring that pre- and post-detonation monitoring is completed in daylight; restricting detonations to good sea conditions; more guidance on the use of ADDs; caution and guidance on the use of scare charges; requiring that reports and data are submitted to JNCC as well as the relevant regulator; and recommending that MMOs and PAM operators perform thorough checks of their data. Proposals for Marine Mammal Recording Forms specific to explosives operations are also made.

Contents

1 Introduction

Explosives are used in UK waters primarily for decommissioning oil wells that are no longer in production and for clearance of unexploded ordnance (UXO), the latter often being required during the development of offshore wind farms (OWF). The use of explosives creates high levels of impulsive noise (Brand 2021a, 2021b). Anthropogenic noise in the world's oceans, and its potential impacts on marine mammals and other marine fauna, has attracted much attention in recent years. Potential impacts of noise on marine mammals include behavioural changes, masking of biologically important sounds and, if received levels are high enough, injury (Richardson *et al.* 1995). Impulsive noise, such as that produced during the detonation of explosives, poses a higher risk of auditory injury to marine mammals than non-pulsed noise, due to the high peak levels and rapid rise time that characterise impulsive sounds (Southall *et al.* 2007). In addition to auditory injury, the shock wave produced during detonations has the potential to cause blast injuries (Yelverton *et al.* 1973; Young 1991; Ketten *et al.* 1993; Ketten 1995, 2006; Danil & St Leger 2011; Koschinski 2011; US Navy 2015; Siebert *et al.* 2022).

European Protected Species (EPS) are protected from deliberate killing, injury and disturbance under the Conservation of Habitats and Species Regulations 2017 (and similar legislation for Scottish and Northern Irish inshore waters) and the Conservation of Offshore Marine Habitats and Species Regulations 2017. Marine EPS whose natural range includes UK waters consist of cetaceans, marine turtles, and the Atlantic sturgeon (turtles and the Atlantic sturgeon are at the limit of their range in UK waters and only occur in low numbers). To reduce the risk to marine mammals in UK waters, the Joint Nature Conservation Committee (JNCC) has developed a suite of mitigation guidelines covering geophysical surveys, pile driving and the use of explosives. The guidelines for explosive operations were first introduced in 2009 and were revised in 2010 (JNCC 2010a); the 2010 version was current throughout the period covered by this report. The guidelines have various provisions, including the requirement to monitor for marine mammals prior to commencing detonations and delay the detonations if a marine mammal is detected within a specified mitigation zone. Monitoring is conducted visually by Marine Mammal Observers (MMOs) but may also be conducted acoustically by Passive Acoustic Monitoring (PAM) operators. For some projects, acoustic deterrent devices (ADDs) may be recommended to deter marine mammals from the area immediately prior to operations and it is recommended that charges should be detonated in a sequence of increasing size. Monitoring must continue for a short period following the detonation to look for any evidence of impacts on marine life. The primary role of the MMO or PAM operator is to provide advice to enable the crew to comply with the JNCC guidelines and hence mitigate potential negative impacts of explosives operations on marine mammals. MMOs and PAM operators also record data on the operations, the watches and any marine mammals detected using standardised Marine Mammal Recording Forms (JNCC 2012a).

Analysis of mitigation and monitoring data is important for evaluating the effectiveness of mitigation measures (Nowacek *et al.* 2013; Nowacek & Southall 2016). Periodic analysis has been undertaken of MMO and PAM data from geophysical surveys in UK waters (e.g. Stone 2023a, 2023b). The current study presents a similar analysis of MMO and PAM data from explosives operations in UK waters between 2010 and 2021 to assess both compliance with JNCC guidelines and marine mammal behavioural responses to explosives. The study includes data from decommissioning projects in the oil and gas industry (O&G) and clearance of UXO (UXO clearance was undertaken for the O&G industry, the OWF industry and for electrical interconnector cables).

2 Methods

2.1 Marine mammal observations and effort

Marine mammal observations were undertaken during projects using explosives in UK waters. This report examines all data since the publication of the JNCC guidelines in 2010 until 2021.

Visual watches for marine mammals were carried out during daylight hours. Observers ranged from biologists experienced in marine mammal surveys to non-scientific personnel who in many cases had undergone JNCC-recognised MMO training (https://jncc.gov.uk/our-work/marine-mammal-observer-training/). In addition, PAM was utilised on some projects. Some visual observations were also carried out whilst on transit to sites, but PAM was only undertaken whilst on site.

MMOs and PAM operators completed standard Marine Mammal Recording Forms that require that effort (number of hours of visual or acoustic monitoring) is recorded in addition to detections of marine mammals. Several versions of these forms have been issued over the years (latest version JNCC 2012a), but all versions are compatible and allowed data to be included in the database. There are currently four tabs within this form:

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

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

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

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

2.2 Data quality control

Only data of acceptable quality were entered into the database and subject to analysis. Data checks were applied consistently following a standard list of over 60 checks (Barton 2022). Examples included: checking that operational activity was accurately recorded during observation effort; that positions were credible given the details of the project and (for moving vessels) the time interval and speed of the vessel; that species identity corresponded with the description and/or photograph; and that there was reasonable confidence that behaviour had been recorded accurately (e.g. not an unusually high proportion of sightings by one observer exhibiting the same behaviour). Any errors found were corrected where possible. Only data considered accurate or that had minor inaccuracies that could be corrected were entered into the database. Data with key information missing or errors that were not able to be corrected were discarded.

The recording forms were designed for geophysical surveys and, whilst the use of scare charges could be recorded as a soft start, there was no facility for recording the use of ADDs. Additional data regarding the timings of ADD operation, where available, were added to the forms prior to inclusion in the database; start and stop times were added to the Operations form while source activity on the Effort and Sightings forms were amended where relevant to reflect ADD use. Similarly, the Operations form did not have the facility to record times of the post-detonation search separately to the pre-detonation search, but the relevant search times recorded on the Effort form (or entered as a combined pre- and post-detonation search on the Operations form) were entered separately on the Operations form prior to inclusion in the database.

Following the quality control process, data from a total of 32 projects were included in the database and available for analysis, spanning the period from 2010 to 2021. Of the 32 projects in the database, 16 were decommissioning projects for the O&G industry and 16 were UXO clearance (nine for the OWF industry, five for the O&G industry and two for electrical interconnectors).

2.3 Explosives operations

Of the 32 projects entered into the database, 31 used high-order detonations using a variety of explosives; where recorded, nitromethane and Semtex were the most common. The net explosive quantity (NEQ) used was not always recorded. Where recorded, for decommissioning NEQs of up to 86kg were used, with 58% using an NEQ exceeding 30kg. For UXO clearance, donor charges with NEQs of up to 25kg were used, with 95% being 10kg or less, whilst the UXOs ranged between 20kg and 560kg. The source level of the explosions was rarely recorded, but where noted was up to 279 $dB^{pk\text{-}pk}$ re. 1 μPa @ 1m.

One UXO clearance project used a low-noise alternative to high order clearance, involving the use of two simultaneous donor charges of 750g NEQ each.

For ten decommissioning projects and 11 UXO clearance projects, ADDs were used to deter marine mammals before detonations commenced. In most cases where the type was recorded, a Lofitech Seal Scarer was used, although two decommissioning projects used Aquamark 210 devices. Most projects using ADDs used just one device; 22% of decommissioning projects and 33% of UXO clearance projects using ADDs used two devices simultaneously. The Lofitech Seal Scarer emits an acoustic signal with a fundamental frequency of 14.6kHz and a source level of 204 dB^{pk} re. 1 μPa @ 1m, while the

Aquamark 210 emits frequencies of 5-150kHZ with a source level of 150 dB^{pk} re. 1 μPa @ 1m (McGarry *et al.* 2017).

Six UXO clearance projects used scare charges prior to the main detonation. Between one and five charges were used in a sequence, with three charges being most common. Two projects varied the number of scare charges based on the size of the UXO to be disposed of. Where multiple scare charges were used, they were typically detonated at five-minute intervals, with a progressive increase in charge size with each subsequent detonation. Although one project used a single charge of 100g NEQ, typically the first charge was 50g NEQ with an increase in NEQ of 50g with each subsequent detonation, up to a maximum of 250g NEQ when five charges were used. ADDs were used prior to the scare charges on five of the six projects where scare charges were used.

2.4 General trends in survey effort and species distribution

Maps of effort and species distribution were plotted using DMAP for Windows and show the 200m (short dashed line) and 1,000m (long dashed line) isobaths. For convenience, offshore oil and gas quadrants and blocks were used to plot maps for both decommissioning and UXO clearance projects (one quadrant = 1° latitude x 1° longitude rectangle, comprising 30 blocks measuring 10' latitude x 12' longitude). Effort maps were plotted after summing the amount of effort in each quadrant where the watch started. Individual species maps are included in Appendix 1. Species maps were plotted after summing the number of individuals of each species in each offshore oil and gas licensing block.

2.5 Analysis of compliance

Compliance with the JNCC explosives guidelines and licence conditions (where known) was examined for all detonations. Misfires were included (except where specified) as mitigation should have been in place the same as for successful detonations. Where appropriate, data for decommissioning projects were analysed separately from UXO clearance projects in order to assess practices on each type of operation.

2.5.1 Noise abatement

Noise abatement is not included in the current explosives guidelines but may be required as a licence condition. Where available, licences were examined to establish whether any form of noise abatement was required, such as the use of a bubble curtain. For projects where noise abatement was required, MMO reports were examined to assess compliance with this requirement.

2.5.2 MMOs and PAM operators

The number of dedicated MMOs per project was assessed for the different types of project. Where PAM was used, the number of PAM operators was also assessed.

2.5.3 Use of PAM

The proportion of projects using PAM was assessed for the different types of project. Where licences were available for examination, whether PAM was used was checked for those projects where PAM was required as part of the licence.

2.5.4 The pre-detonation search

Pre-detonation searches were required prior to any detonation. A search of adequate duration was defined as beginning 60 minutes before the detonation and not terminating prior to the detonation.

The proportion of occasions when visual pre-detonation searches were adequate was assessed for detonations during daylight hours on all projects. Acoustic searches during daylight were assessed for all projects where PAM was used and also for those projects where it was known that the licence required PAM to be used (where licences were available for examination). There were only a few detonations at dawn, dusk or during the night, but monitoring prior to these was also assessed.

2.5.5 Acoustic deterrent devices

For projects where licences (where available for examination) required that ADDs were used, the data were examined to ascertain whether they were used and whether any requirements for the duration of their use were complied with.

The duration of ADD use was also examined for all projects using ADDs, whether required by licence or not. The JNCC explosives guidelines say that ADDs should be switched on during the pre-detonation search, but do not specify a period of monitoring beforehand. Nevertheless, the data were examined to see what monitoring was in place prior to the use of ADDs. The guidelines say that ADDs should be switched off immediately once detonations commence; when ADDs were switched off in relation to detonations was therefore examined.

The JNCC guidelines do not address what should happen if a marine mammal is detected when ADDs are active. Any detections of marine mammals in the mitigation zone while the ADD was active were examined to establish what procedures were put in place.

2.5.6 Delays in operations

The number of occasions when a delay in operations was required due to the presence of marine mammals in the 1km mitigation zone was compared to the number of detonations. The JNCC guidelines say that detonations should not commence within 20 minutes of marine mammals being detected in the mitigation zone; procedures enacted in the event of a marine mammal occurring in the mitigation zone during the pre-detonation search were assessed.

2.5.7 Scare charges

The JNCC guidelines do not include the use of scare charges as a mitigation measure, but as these were sometimes used on UXO clearance projects their use was examined. For the six UXO projects where scare charges were used, the number of charges and minimum, maximum and mean duration of their use was assessed. The duration of monitoring beforehand and the time between the last scare charge and the detonation was also examined.

Any detections of marine mammals in the mitigation zone during the sequence of scare charge detonations were examined to establish what procedures were put in place.

2.5.8 Sequencing of charges

The JNCC guidelines say that where possible the order in which charges are detonated should be controlled with a progressive increase in charge size. For projects where there was more than one detonation, the order in which charges were detonated was examined in relation to the NEQ (where recorded).

2.5.9 Detonations at night or in poor conditions

The JNCC guidelines say that detonations should only commence during hours of daylight and good visibility and that observers should be able to monitor the full extent of the mitigation zone. The number of detonations at night or in poor visibility was assessed; for poor visibility this could only be assessed where weather had been recorded on the Effort forms. Poor visibility on the Effort forms is defined as < 1km. Moderate visibility is defined as 1-5km, so potentially in some periods of moderate visibility the full extent of the mitigation zone may not have been visible, depending on the observer's location. Therefore, the number of detonations in both poor and moderate visibility, as recorded on the Effort forms, was assessed. The guidelines also recommend that PAM is used during periods when the sea state is not conducive to visual mitigation, therefore this was also assessed; poor sea conditions were defined as 'rough' sea states or swell > 4m and suboptimal conditions as 'choppy' sea states or 2-4m swell.

2.5.10 Post-detonation search

Post-detonation searches were required after any detonation, looking for evidence of any impacts on marine life. Due to the nature of the search, post-detonation searches had to be visual. A search of adequate duration was defined as beginning at the time of detonation and not terminating until 15 minutes had elapsed since the detonation. The proportion of occasions when post-detonation searches were adequate was assessed for all detonations (except misfires).

For all post-detonation searches carried out, MMO reports and data were examined for any records of evidence of impacts on marine life, e.g. dead fish at the water surface.

2.6 Response of marine mammals to explosives

2.6.1 Analysis and statistical tests

For some analyses, it was not appropriate to use all the data in the database. For example, some sightings or acoustic detections had no accompanying effort data so could not be used where detection rates per unit effort were calculated; for other aspects of analysis, effort data was not necessary, and all sightings and acoustic detections were used.

Due to the differences in the methodology (see Section 2.3), it was not appropriate to analyse high-order detonations together with low-noise methods. There were no detections during the project that used a low-noise method, so it was not possible to examine the response of marine mammals to this method.

For some analyses, other variables had the potential to influence the results. Weather conditions influence the ability of observers to detect marine mammals (e.g. Northridge *et al*. 1995; Teilmann 2003; Hammond *et al*. 2013). If weather was likely to bias the results, periods with the same weather conditions were compared where possible. Location, season, observer ability and monitoring method (visual or acoustic) also needed to be considered as potential influences for some analyses.

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

Results are presented for individual species where sample size permitted. Where the species level sample size was too small, (this varied depending on the test being used), groups of combined species were used (e.g. all seals, all cetaceans, all mysticetes, all delphinids). These combined species groups comprised all identified and unidentified animals within that taxonomic grouping (Table 1).

Table 1. Division of marine mammal species into combined species groups for analysis.

Pinnipeds	Mysticetes	Delphinids
Seal sp.	Humpback whale	Long-finned pilot whale
Grey seal	Minke whale	Killer whale
Harbour seal		Dolphin sp.
		Bottlenose dolphin
		White-beaked dolphin

2.6.2 Detection rates prior to and post detonations

Monitoring often commenced in the days prior to operations commencing, as preparations were made, and often continued in the days after detonations. Detection rates were compared between all periods prior to the detonation and all subsequent to the detonation. Due to low numbers of detections, data could only be compared for the combined groups of all seals or all cetaceans. As there was only one project using a low-noise method, data were only compared for high-order detonations.

Matched pairs (prior to detonation versus post detonation) were used where for each pair the project, ship, observer / PAM operator, monitoring method (visual or acoustic) and weather conditions (sea state, swell and, for visual observations, visibility) were the same. As projects were mostly of relatively short duration, temporal variation was controlled to some extent by having all observations within each matched pair being within the same project. Spatial variation was also controlled by comparing pairs within the same project, as projects were located at specific sites. Monitoring effort and detections whilst on transit to sites were excluded. The resulting matched pairs (prior to detonation versus post detonation) were tested using the Wilcoxon signed ranks test, a non-parametric test appropriate for two related or matched samples that ranks the differences between each pair. It compares both the direction of the difference in each pair (i.e. which is greater) and also the magnitude of the difference (i.e. by how much is it greater). The Wilcoxon signed ranks test can be performed on small samples, with significant results being able to be detected with sample sizes as low as five matched pairs (Siegel & Castellan 1988).

When comparing detection rates prior to and post detonations, the post detonation periods included monitoring up to 10 days after the detonation. Potentially any initial decline in detections could have been masked if animals later returned to the area. Initial examination of the data showed that there were fewer detections in the hours following the detonation on the detonation date than there were either prior to the detonation or in the days subsequent to the detonation. The analysis was therefore repeated comparing detection rates in the hours following the detonation on the detonation date to all other periods. Due to low numbers of detections data could only be compared for grey seals and the combined groups of all seals and all cetaceans and only for high-order detonations. Matched pairs were again used, this time comparing the hours following detonation versus all other times. The project, ship, observer / PAM operator, monitoring method (visual or acoustic) and weather conditions (sea state, swell and, for visual observations, visibility) were the same within each pair and monitoring effort and detections whilst on transit to the site were excluded. The resulting matched pairs (hours following detonation versus all other times) were tested using the Wilcoxon signed ranks test.

2.6.3 Closest distance of approach to the detonation site

When marine mammals were detected prior to detonations, often the closest distance of approach to the detonation site was not recorded. Owing to this, it was not possible to compare the closest approach prior to detonation with that post detonation, as sample sizes prior to the detonation were low. However, by combining observations prior to the detonation with those on days after a detonation, it was possible to compare the closest approach in the hours following a detonation on the detonation date with the closest approach at all other times. Distance estimation with PAM is not as accurate as with visual monitoring (Stone 2015, 2023a), so only visual detections (with or without accompanying effort data) were used. Only data from high-order detonations were used.

Detonations were less likely to be conducted in rough weather conditions and in such conditions, animals would be harder to detect at distance; this could result in bias towards closer distances in the days prior to or subsequent to detonations. However, sample sizes were such that the influence of weather could not be controlled for, nor was it possible to account for observer bias.

The closest distance of approach of animals to the detonation site during an encounter was compared (after a detonation on the detonation date versus all other times) using the Wilcoxon-Mann-Whitney test. Scores were ranked and W_x was determined by summing the ranks in the smallest group. The Wilcoxon-Mann-Whitney test can be performed on small samples, with significant results being able to be detected with sample sizes as low as three in each group (Siegel & Castellan 1988).

2.6.4 Behaviour

Only visual sightings were used to examine behaviour of marine mammals. All sightings on site were used, including those without associated effort and during any weather conditions. Behaviour before and after detonations was examined, although sample sizes were insufficient to permit statistical analysis. Behaviour of any animals seen during the use of ADDs or scare charges was also examined.

3 Results

3.1 Data submission and quality

Between 2010 and 2021, there were 55 O&G decommissioning projects recorded as being licensed. Records show that ten of these projects were downhole detonations at depths where mitigation was not required (generally deeper than 700m below the seabed, although during 2021 the threshold in some cases changed to 100m below the seabed). A further six projects utilised other methods (e.g. cutting tools) or stated that explosives were a contingency option so potentially explosives were not used in these cases. MMO reports and/or data were received from only 19 of the remaining 39 projects. Of the 19 projects where reports and/or data were received, four had no MMO report and for three the submitted data were discarded due to poor quality. For two projects, the data were in Word or pdf format and had to be transcribed into the Excel recording forms (one of these was a project where the data were ultimately discarded). Data for 16 O&G decommissioning projects were of acceptable quality to be included in the database after checks and corrections.

There were 23 licensed UXO clearance projects between 2010 and 2021 of which 16 submitted MMO reports and/or data. Of these 16 projects, one lacked a report but sent data, and three (one in whole and two in part) provided data in pdf format that required transcribing into the Excel recording forms, but all 16 projects had data that were usable after checks and corrections. Of the seven UXO projects that did not submit MMO reports or data, one corresponding license had no mention of reporting requirements but licenses were unavailable for the rest.

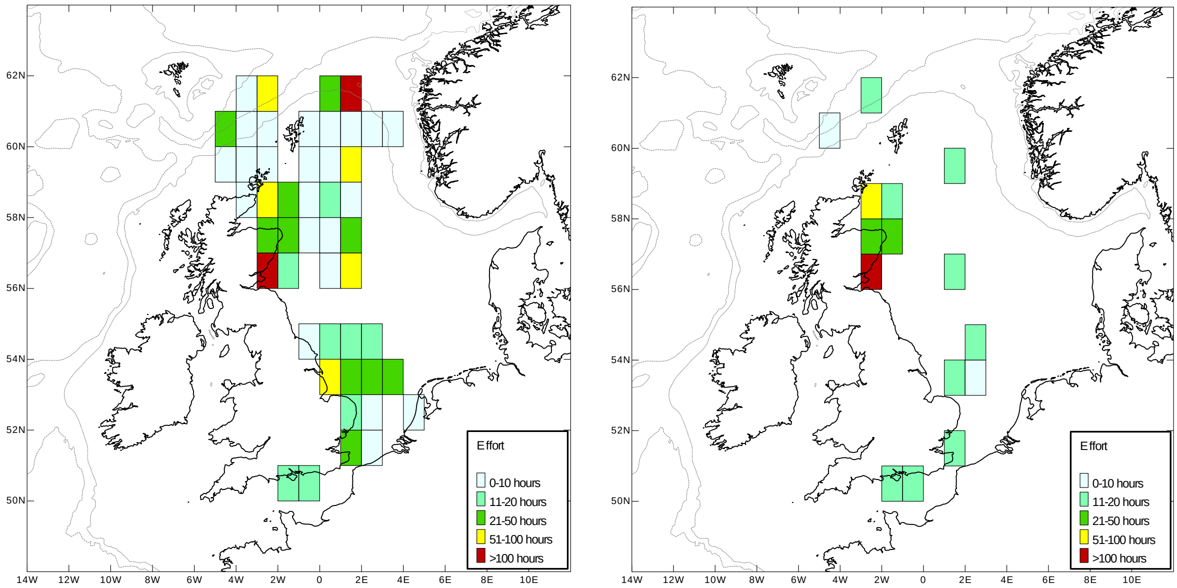
Where data were usable, corrections were still required prior to inclusion in the database. Typical errors included: source activity on the Effort form not corresponding with activity recorded at the appropriate time on the Operations form (or combining source activities as variable over a period rather than recording each activity separately on the Effort form); recording times using different time zones (BST was sometimes used instead of UTC); misaligning columns in the spreadsheet such that data were entered into the wrong columns for part of a project; and errors in recording whether positions of longitude were east or west of the Greenwich meridian.

Relevant information not currently requested on the recording forms was sometimes, but not always, included on the forms or in MMO reports. Most (78%) projects included in the database noted details of the type of explosive in the MMO report and most (75%) also recorded the NEQ (for UXO clearance projects this was the NEQ of the donor charge). However, only 38% of UXO clearance projects recorded the estimated NEQ of the UXO. For 90% of the projects where ADDs were used the timing of ADD use was noted somewhere, usually in the MMO report but sometimes added to the recording forms in varying formats. All six projects using scare charges recorded the times of their use, usually on the recording forms but again in varying formats. Although the formats varied, the availability of data on the timing of ADD or scare charge use enabled this information to be collated in a consistent format prior to inclusion in the database.

3.2 Overview of survey effort and species distribution

Observations encompassed 48 quadrants (1° rectangles) throughout UK waters, including some that were passed in transit to or from the site when operations were not ongoing, but sightings were still recorded. A total of 1,698 hours 27 minutes were recorded as monitoring for marine mammals between 2010 and 2021; of this, 1,264 hours 04 minutes were recorded for visual monitoring and 434 hours 23 minutes for acoustic monitoring. 46.0% of the time spent monitoring was prior to the first detonation of a project, while 54.0% was after the detonation(s) had commenced. ADDs were active for 7.6% of the total time spent monitoring and scare charges were being used for 2.5% of the time.

There was much less acoustic monitoring than visual monitoring (Figure 1). Whilst some monitoring was undertaken while vessels were in transit, which sometimes was from foreign ports, this was always visual monitoring with PAM being limited to periods spent on site. Only 11.2% of monitoring effort was whilst on transit.

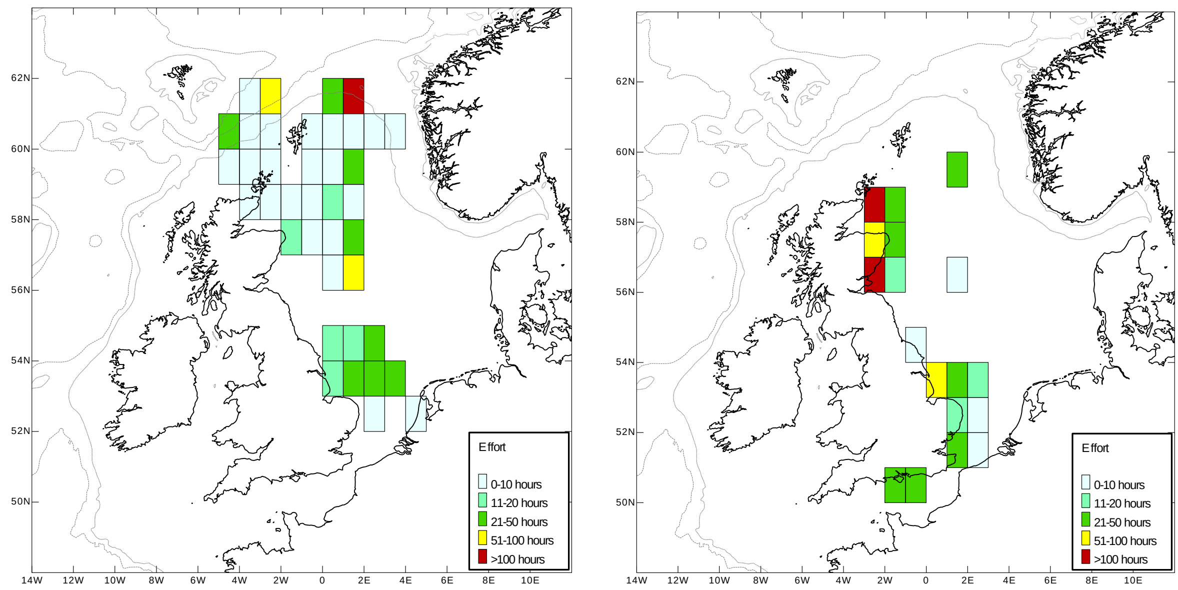


a) Visual monitoring

b) Acoustic monitoring

Figure 1. Visual and acoustic monitoring effort during explosives projects, 2010-2021 (scale 1° quadrants).

Although there were data from the same number of O&G decommissioning projects and UXO projects, monitoring effort covered a wider area for decommissioning (Figure 2). The total time spent monitoring on each was similar: 808 hours 21 minutes for O&G decommissioning projects and 890 hours 06 minutes for UXO projects. However, acoustic monitoring was used relatively more often on UXO projects (38.9% of monitoring was acoustic) than on O&G decommissioning projects (10.9% of monitoring was acoustic).

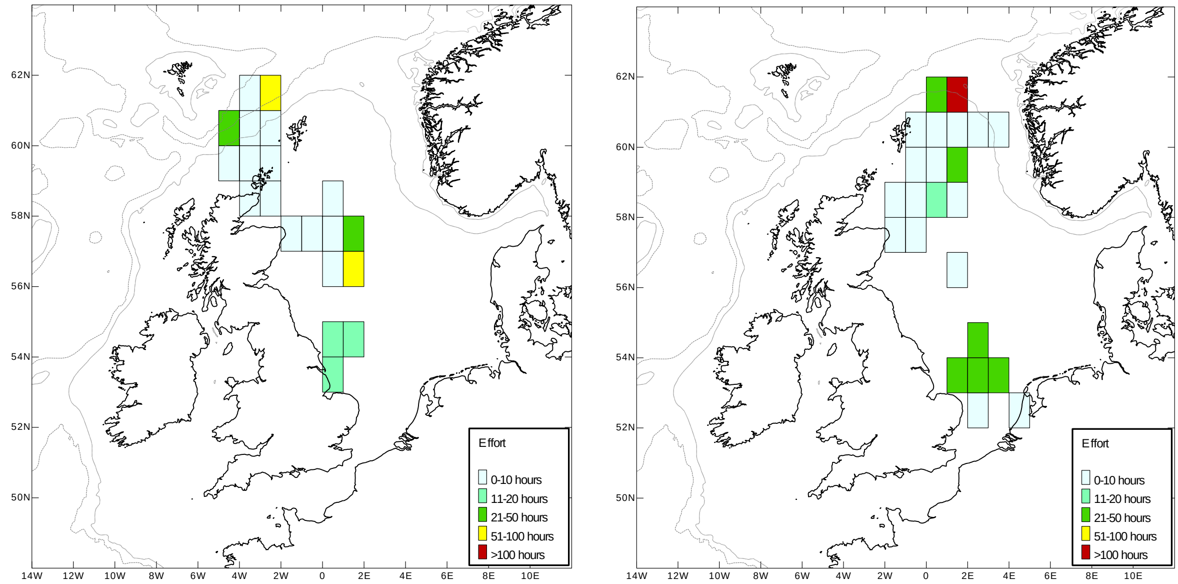


a) O&G decommissioning projects

b) UXO projects

Figure 2. Monitoring effort (visual and PAM combined) during O&G decommissioning and UXO projects, 2010-2021.

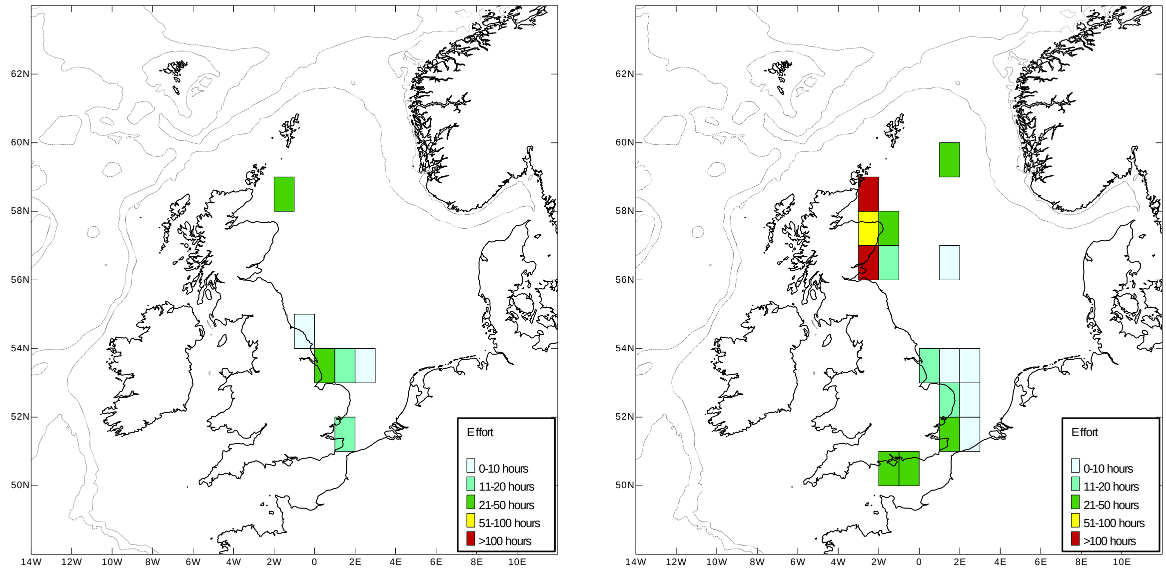
There were temporal variations in monitoring effort between years (Figure 3 and Figure 4). For both decommissioning and UXO projects, more time was spent monitoring between 2016 and 2021 than in earlier years, but this was particularly evident for UXO projects. There was a marked increase in monitoring effort on UXO projects since 2019, reflecting an increase in the number of UXO projects but also an increase in the number of items of ordnance to be disposed of within projects. There was also a seasonal variation in monitoring effort with more decommissioning projects taking place during the summer months (Figure 5) and more UXO clearance taking place during the spring (Figure 6).



a) 2010–2015

b) 2016–2021

Figure 3. Temporal variation in monitoring effort (visual and PAM combined) during O&G decommissioning projects throughout the period from 2010–2021.



a) 2010–2015

b) 2016–2021

Figure 4. Temporal variation in monitoring effort (visual and PAM combined) during UXO projects throughout the period from 2010–2021.

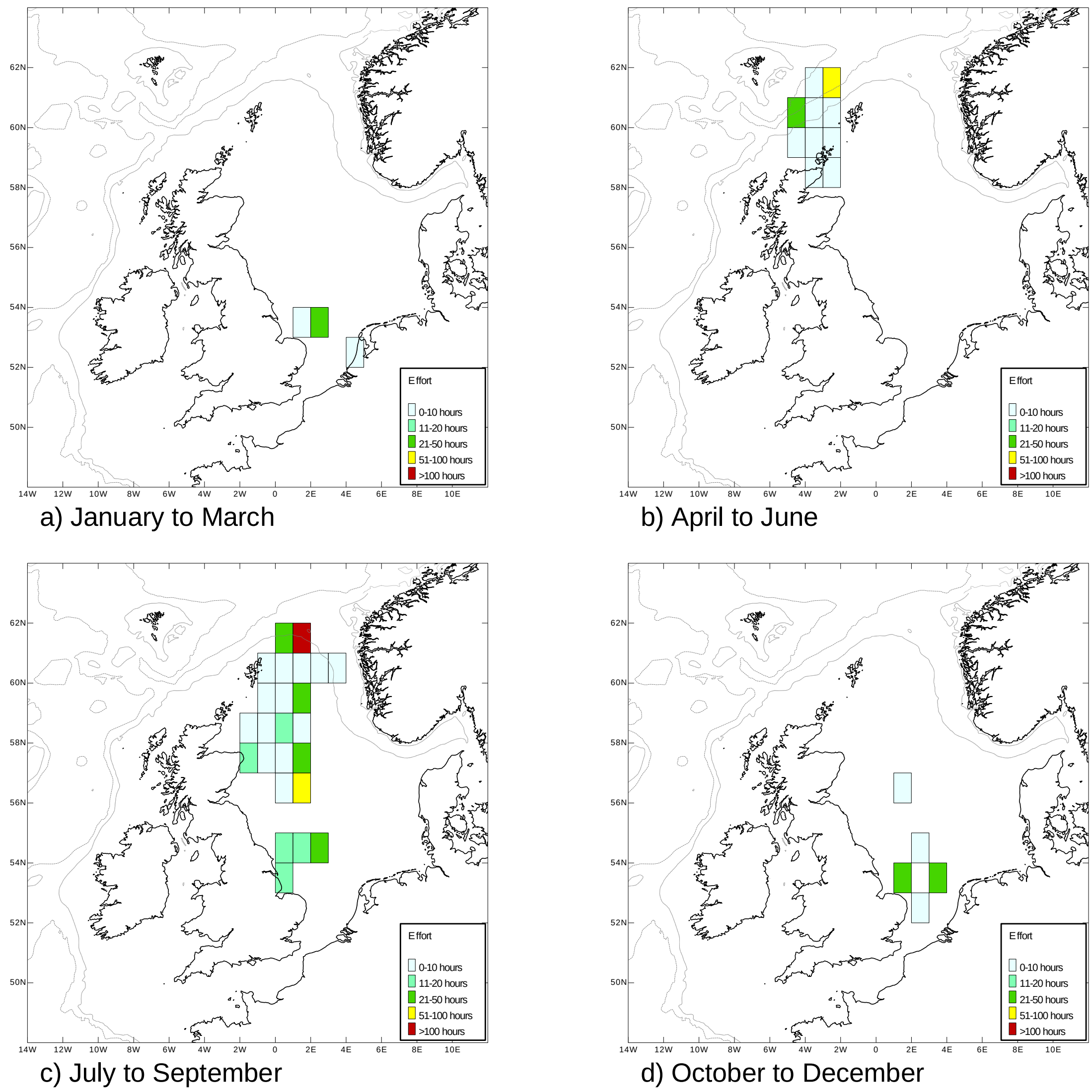


Figure 5. Seasonal monitoring effort (visual and PAM combined) during O&G decommissioning projects from 2010–2021 (all years combined).

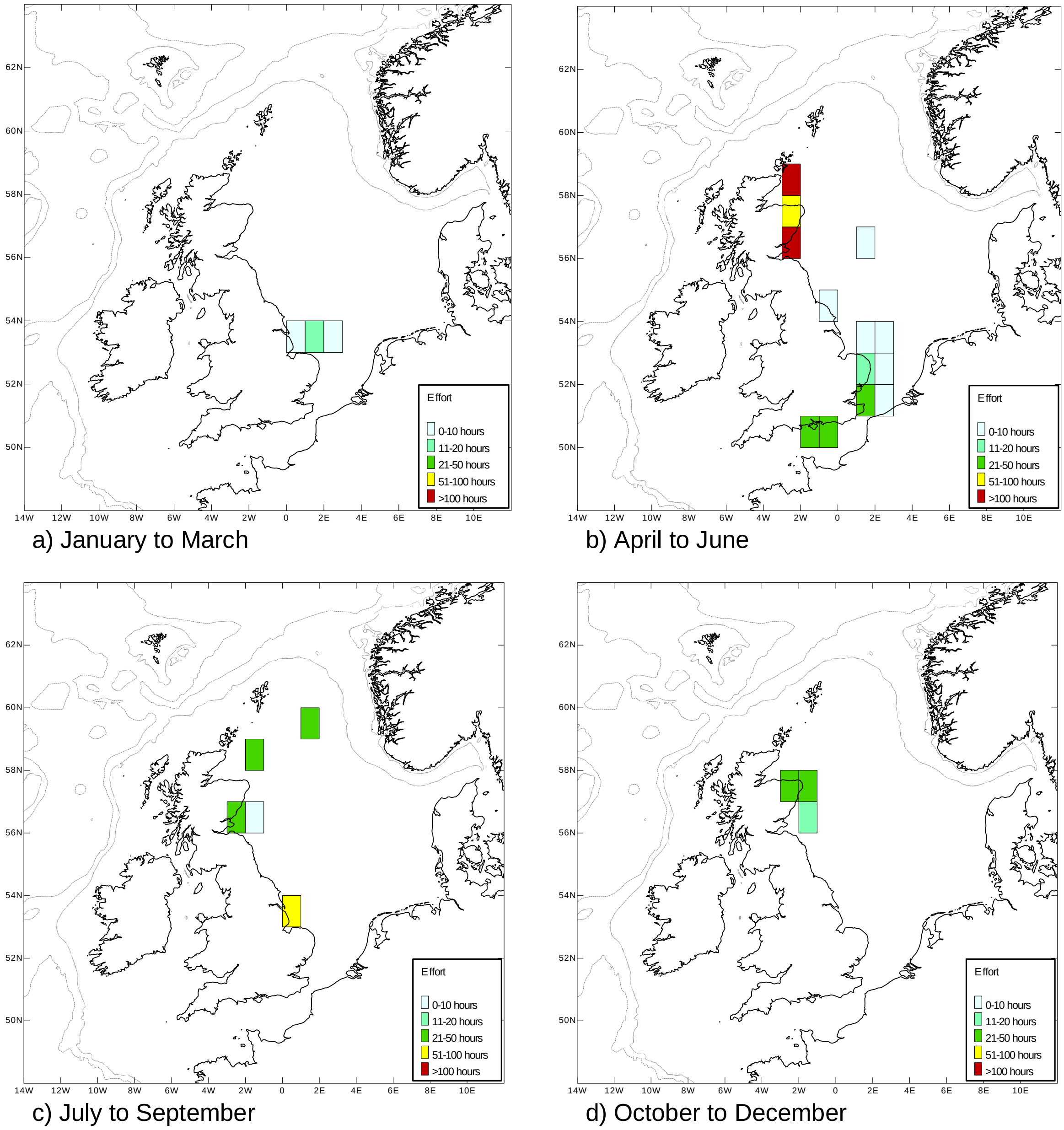


Figure 6. Seasonal monitoring effort (visual and PAM combined) during UXO projects from 2010–2021 (all years combined).

A total of 92 marine mammal sightings or acoustic detections comprising 211 individual animals were encountered, including 35 sightings whilst on transit to or from the site. Most were seen visually (90) with just one detected only acoustically and one detected by both visual and acoustic means. The most frequently encountered identified species was the minke whale (Table 2), followed by the grey seal and the harbour porpoise (an encounter being one or more animals occurring together). Other species were seen infrequently.

Table 2. Marine mammal encounters during projects using explosives in UK waters from 2010–2021 and estimated number of individuals. Where number of individuals could not be determined with PAM a minimum number of one was assigned.

Species	No. sightings (and no. individuals)		No. acoustic detections (and no. individuals)		No. detections both visual and acoustic (and no. individuals)	
Seal sp.	15	(15)				
Grey seal	17	(24)				
Harbour seal	7	(9)				
Cetacean sp.	1	(1)				
Whale sp.	3	(3)				
Large whale sp.	1	(1)				
Humpback whale	1	(1)				
Minke whale	18	(22)				
Long-finned pilot whale	2	(11)			1	(8)
Killer whale	2	(7)				
Dolphin sp.	5	(27)	1	(1)		
Bottlenose dolphin	4	(43)				
White-beaked dolphin	3	(15)				
Harbour porpoise	11	(23)				
Total	**90**	**(202)**	**1**	**(1)**	**1**	**(8)**

The distribution of sightings and acoustic detections reflected survey effort, with most sightings / detections occurring in the southern and northern North Sea with a few further north to the north and west of Shetland (Figure 7). Some sightings were seen whilst in transit, including clusters of sightings to the west of Orkney and off the Humber estuary.

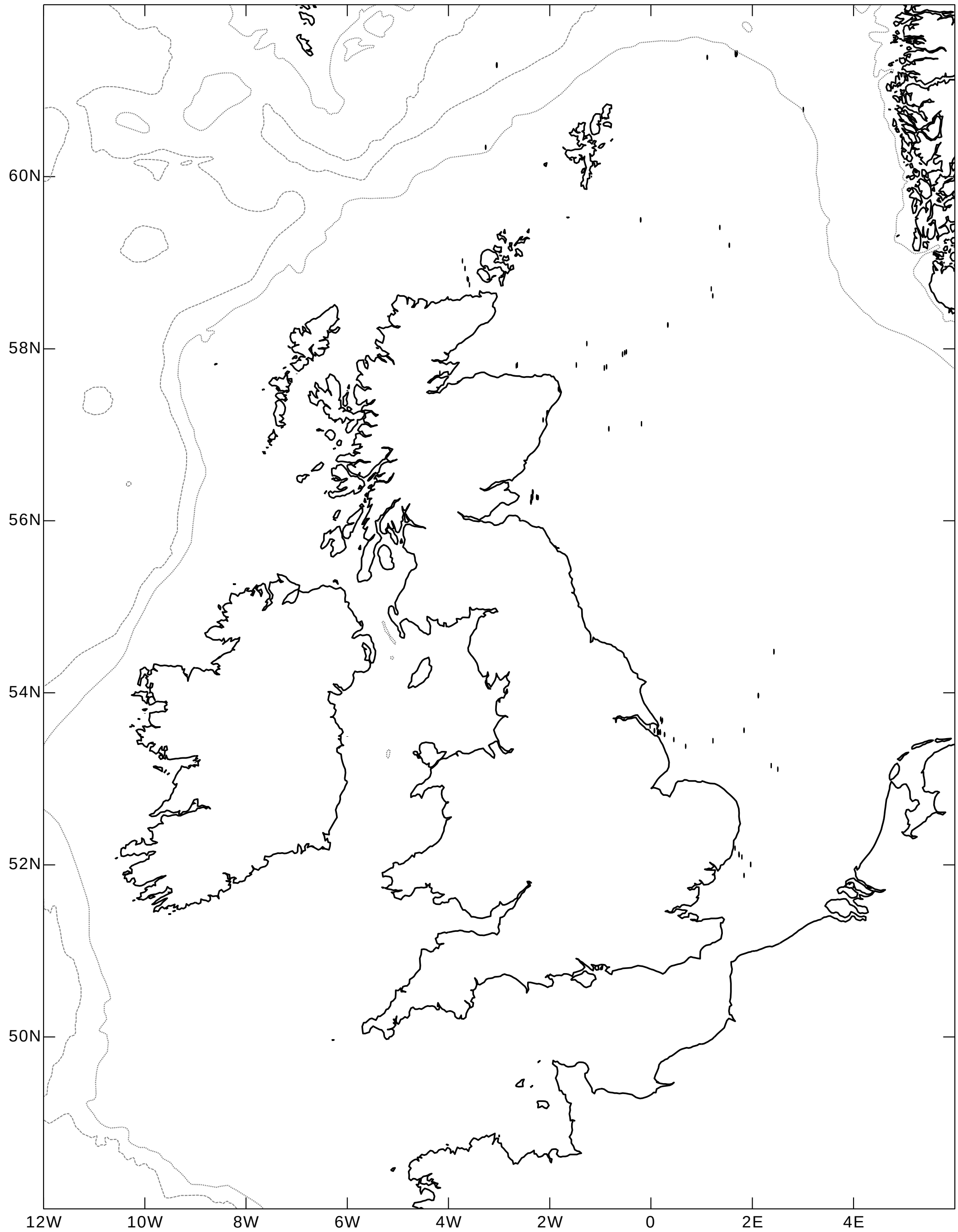


Figure 7. Encounters with marine mammals during projects using explosives, 2010–2021.

Individual species maps are included in Appendix 1 (Figure 9 to Figure 17). Seals were encountered mostly close to the coast in the North Sea (Figure 9 and Figure 10). Grey seals were seen more often than harbour seals, with most being seen off north-east Scotland, particularly along the Aberdeenshire coast and off the Firth of Forth. Both harbour and grey seals were also seen further offshore in the southern North Sea.

There was only one sighting of a large rorqual whale, a humpback whale seen off the Firth of Forth (Figure 11). The smaller minke whale was seen in the northern North Sea and to the north and west of Shetland and Orkney, although highest numbers were seen off the Firth of Forth in a similar location to the humpback whale (Figure 12).

As well as having concentrations of minke whales and grey seals and a sighting of a humpback whale, the area off the Firth of Forth also had killer whales, bottlenose dolphins and harbour porpoises (Figure 14, Figure 15 and Figure 17). These sightings occurred during UXO clearance at one OWF, which was the project with the highest number of marine mammal sightings overall. It was also the project with the highest number of detonations and consequently the most hours spent monitoring.

Apart from those seen of the Firth of Forth, killer whales occurred further north to the north-east of Shetland (Figure 14). Long-finned pilot whales also had a northern distribution, being seen in the northernmost parts of the North Sea and in deep waters to the west of Shetland (Figure 13).

Bottlenose dolphins were seen mostly close inshore off the coast of Aberdeenshire and in the Moray Firth (Figure 15). White-beaked dolphins had a more offshore distribution, mainly in the northern North Sea and to the north-east of Shetland (Figure 16). Harbour porpoises had a widespread distribution throughout the northern and southern North Sea in both inshore and offshore waters (Figure 17).

3.3 Compliance with guidelines

3.3.1 Noise abatement

There were only two projects where any form of noise abatement was required; in both cases bubble curtains were used. Both were UXO clearance projects in 2018 and 2019. For both projects, UXOs with a high NEQ were due to be detonated (220kg and 260kg), although there were also other projects with high NEQ UXOs where the licence did not require the use of a bubble curtain. The licences required bubble curtains to be used in water currents less than $0.5ms^{-1}$ (although one licence applied this limit to deployment only, with operation of the bubble curtain in currents of up to $1.5ms^{-1}$).

During these two projects, bubble curtains were used for four detonations, three (220kg NEQ) on one project and one (260kg NEQ) on the other. For the first project there were no detonations where the bubble curtain was not used. The diameter of the bubble curtain was 80m and it was started 15 minutes before the detonation. On the other project, there was one other detonation where the bubble curtain was not used, but this was a smaller UXO (32 kg NEQ) and the licence said that the bubble curtain would not be required for UXOs with an NEQ less than 50kg. When the larger UXO was detonated, the bubble curtain was used but there were no further details.

There were two further UXO clearance projects where bubble curtains were mentioned in the licence; one (in 2019) where a bubble curtain was required for UXOs with NEQs greater than 50kg and the other (in 2017) that noted a bubble curtain should be used "where appropriate". Neither used bubble curtains; the project where a bubble curtain was required for larger UXOs only had UXOs smaller than 50kg NEQ.

An alternative to high-order detonation was used on only one UXO clearance project. This method was used for four UXOs on that project, although the NEQ of the UXOs was not recorded.

3.3.2 MMOs and PAM operators

The total number of personnel in the mitigation team varied between one and three for decommissioning projects and one and four for UXO clearance projects. The average number of mitigation personnel was 1.7 for both types of projects. However, a single person was more common on UXO clearance projects than decommissioning projects (53% and 44% of projects respectively). Where additional personnel were used, this was more likely to be another MMO on UXO clearance projects and a PAM operator on decommissioning projects.

UXO clearance projects used two or more dedicated MMOs slightly more often than decommissioning projects (22% and 19% of projects respectively). One UXO project had three dedicated MMOs. However, the majority of projects of both types used just one dedicated MMO.

Where PAM was used, in all cases there was only one PAM operator. On four of the 11 UXO projects using PAM, a single person was used as a dual role MMO / PAM operator. In one case, this person was doing visual observations whilst monitoring remote headphones for PAM. In another case, there was a single vessel with a single dual role MMO / PAM operator for part of the project, and two vessels each with a single dual role MMO/ PAM operator for the other part. In the first part PAM was not used while in the second part PAM was used for a portion of each pre-detonation search. For the two other projects with a single dual role MMO / PAM operator, either visual observations or PAM were used depending on conditions. There were no cases where a single person undertook a dual role on decommissioning projects, although PAM was used less often on these projects.

3.3.3 Use of PAM

PAM was used on 50% of decommissioning projects and 69% of UXO clearance projects. All projects where the licence (where available for examination) required acoustic monitoring used PAM with the exception of one UXO clearance project. In that project, although the licence required visual and acoustic monitoring, ADDs, scare charges and a bubble curtain, the Marine Mammal Mitigation Plan (MMMP) included all elements except acoustic monitoring (although in the event scare charges were also not used).

Where specified, all but one project using PAM had a hydrophone cable deployed vertically, mostly from the main platform or vessel, but on two occasions from a smaller fast rescue craft. Only one project (a UXO clearance project) recorded using a towed array, this being deployed from a smaller survey vessel separate to the main vessel circling around the UXO location.

There were only two acoustic detections, these being of unidentified dolphins and long-finned pilot whales, the latter being first detected visually.

3.3.4 Pre-detonation search

During the period 2010–2021, there was full compliance with the requirements for visual pre-detonation searches in daylight on decommissioning projects, although it should be noted that two detonations took place at night with no visual search; most searches on UXO projects were also compliant (Table 3). Eight of the nine non-compliant daylight visual searches were due to the search commencing late. Seven of these appeared to be due to the MMO transferring between the main vessel and a smaller vessel, resulting in a gap in monitoring. The other non-compliant search ended prematurely.

Table 3. Percentage (and sample size) of adequate duration visual pre-detonation searches during daylight.

Year	Decommissioning		UXO	
2010	100.0	(1)	-	
2011	100.0	(4)	100.0	(1)
2012	-		-	
2013	-		100.0	(8)
2014	100.0	(2)	-	
2015	100.0	(1)	-	
2016	100.0	(3)	97.4	(38)
2017	100.0	(13)	100.0	(8)
2018	100.0	(3)	100.0	(2)
2019	-		97.2	(36)
2020	100.0	(6)	88.5	(61)
2021	-		100.0	(7)
Total	100.0	(33)	94.4	(161)

On projects where PAM was available, acoustic searches in daylight were often inadequate, both on decommissioning and UXO projects (Table 4). While 15% of inadequate acoustic searches were due to no acoustic search being undertaken, in most cases an acoustic search was conducted but was not long enough (29% of inadequate acoustic searches terminated prematurely, 5% did not start far enough in advance of the detonation, while 51% both started late and ended too soon). On UXO projects, 20% of acoustic searches (where there was a search) were less than ten minutes in duration. Where licences were available for examination, there was only one decommissioning project and five UXO projects where PAM was required to be used as a licence condition. Both acoustic searches for the decommissioning project ended too soon as deployment of the PAM array through the moon pool meant that it had to be recovered 15 minutes prior to the detonation. For most UXO detonations, there was an adequate acoustic search when it was required by licence (Table 5); four of the five UXO clearance projects that required PAM as a licence condition had fully compliant acoustic searches but the fifth project did not use PAM at all.

Table 4. Percentage (and sample size) of adequate duration acoustic pre-detonation searches in daylight on projects where PAM was used.

Year	Decommissioning		UXO	
2010	0.0	(1)	-	
2011	0.0	(4)	-	
2012	-		-	
2013	-		87.5	(8)
2014	0.0	(2)	-	
2015	-		-	
2016	0.0	(3)	0.0	(38)
2017	100.0	(12)	100.0	(8)
2018	33.3	(3)	-	
2019	-		100.0	(33)
2020	-		96.7	(61)
2021	-		66.7	(6)
Total	52.0	(25)	72.1	(154)

Table 5. Percentage (and sample size) of adequate duration acoustic pre-detonation searches in daylight on projects where PAM was required as a licence condition (where licences were available for examination).

Year	Decommissioning		UXO	
2010	-		-	
2011	-		-	
2012	-		-	
2013	-		-	
2014	0.0	(2)	-	
2015	-		-	
2016	-		-	
2017	-		100.0	(8)
2018	-		-	
2019	-		91.7	(36)
2020	-		-	
2021	-		-	
Total	0.0	(2)	93.2	(44)

The JNCC guidelines recommend that detonations are undertaken in daylight. There were two detonations at night on one decommissioning project; there was an adequate duration acoustic search prior to both detonations but due to darkness there was no opportunity for visual monitoring. There was one detonation at dawn on a UXO project and one detonation at dusk on another UXO project. With the dawn detonation, there was a search initially with PAM, but this then switched to a visual search; however, there was a five minute gap in monitoring when switching between methods as there was a single dual role MMO/PAM operator on the project. With the detonation at dusk there was a visual search of adequate duration beforehand.

Some MMO reports from UXO clearance projects noted that vessels were positioned at a stand-off location outside of the mitigation zone, meaning that the far side of the 1km radius mitigation zone was over 2km away from the observation position. Some MMOs noted in their reports that this made it difficult to monitor the full extent of the mitigation zone. In some cases, MMOs observed from a smaller vessel (a fast rescue craft or workboat) within the mitigation zone initially; however the height of eye was then much lower, typically around 2m. One MMO report commented that the low height of eye made it difficult to monitor the full extent of the mitigation zone. On one project where the MMO was on a smaller vessel, three of the four marine mammal sightings were seen on the larger main vessel by personnel not undertaking a dedicated watch, twice by the ship's crew. One UXO project had MMOs on both the main vessel and a smaller vessel and the MMO report included a recommendation that this approach was used for future projects. Acoustic monitoring was sometimes hindered by noise, mainly from vessel thrusters.

3.3.5 Acoustic deterrent devices

ADDs were used on 66% of projects (69% of UXO clearance projects and 63% of decommissioning projects). Overall, they were used before 84% of detonations, more often on UXO clearance projects than decommissioning projects (88% and 60% of detonations respectively). ADDs were almost always used on projects where they were required as a condition of the licence (Table 6). Not all licences specified a duration for ADD deployment – all those where a duration was specified were for UXO clearance projects. The specified durations varied between projects, ranging from 15 minutes (for a project with UXOs of up to 240kg NEQ) to no more than 80 minutes (for a project with UXOs of 220kg NEQ). ADD durations complied with these requirements on only around half of occasions (Table 7). All ADD durations that were not compliant were longer than they should have been. Compliance was lowest when the licence required that ADDs were deployed for 15 minutes, when the majority (82%) of durations exceeded this, with a maximum duration of 2 hours 1 minute. However, most ADD deployments were not excessively prolonged, with 90% lasting less than 40 minutes.

Table 6. Percentage (and sample size) of detonations where ADDs were used beforehand on projects where this was a licence requirement.

Year	Decommissioning		UXO	
2010	-		-	
2011	-		-	
2012	-		-	
2013	-		-	
2014	-		-	
2015	-		-	
2016	-		100.0	(38)
2017	-		100.0	(8)
2018	100.0	(2)	100.0	(2)
2019	-		100.0	(36)
2020	100.0	(5)	-	
2021	-		33.3	(3)
Total	100.0	(7)	97.7	(87)

Table 7. Percentage (and sample size) where the duration of ADD use complied with licence conditions (where durations were specified in the licence).

Year	Decommissioning	UXO	
2010	-	-	
2011	-	-	
2012	-	-	
2013	-	-	
2014	-	-	
2015	-	-	
2016	-	18.4	(38)
2017	-	71.4	(7)
2018	-	-	
2019	-	86.1	(36)
2020	-	-	
2021	-	100.0	(1)
Total	-	53.7	(82)

Some projects used ADDs even though it was not required in the licence. Irrespective of whether ADDs were required in the licence, ADDs were employed for longer on decommissioning projects than on UXO clearance projects (Table 8).

Table 8. Duration of use of ADDs, whether required by licence or not (n = sample size).

Type of project	Minimum duration (minutes)	Mean duration (minutes)	Maximum duration (minutes)	n
Decommissioning	16	42	378	21
UXO clearance	6	29	148	146

Where ADDs were used, on 5% of occasions there was no monitoring immediately beforehand, sometimes when ADDs were deployed far in advance of the pre-detonation search or sometimes because the MMO had to stop monitoring to deploy the ADD (which also resulted in an inadequate pre-detonation search). On 16% of occasions there was a search of less than 30 minutes; on 38% of occasions the search was between 30 minutes and one hour; and on 40% of occasions the search was for more than one hour before ADDs were deployed.

On the majority (81%) of occasions, the ADDs were switched off prior to detonations / scare charges commencing, up to 41 minutes beforehand, although most were not more than five minutes beforehand. On 12% of occasions, the ADDs were switched off at the same time as detonations / scare charges commenced while on 7% of occasions they were switched off afterwards (a maximum of 24 minutes after). There was at least one occasion where ADDs had to be redeployed as the detonation was not ready to commence.

There was one occasion when a marine mammal (a grey seal) appeared in the mitigation zone while the ADD was active, remaining there for 20 minutes. On that occasion, activation of the ADD was continued for longer until the scare charge began 20 minutes after the seal left the mitigation zone.

Several MMO reports noted some issues with the use of ADDs:

- A single MMO had to deploy the ADD, resulting in the MMO having to take a break from monitoring to deploy the device.
- Responsibility for deployment of the ADD was handed to the deck crew so that the single MMO could maintain a watch.
- The ADD was not supplied with a power source.
- The supplied batteries were unable to hold their charge.
- ADDs were supplied with no redundancy in case of failure of the units.
- Potential for damage to the ADD if towed close to the vessel.

3.3.6 Delays in operations

Between 2010 and 2021, there were three occasions when detonations were required to be delayed due to the presence of marine mammals within the mitigation zone. In comparison to the number of detonations, the number of delays required was low, with one delay required for every 67 detonations over the whole period (= 1.5% of detonations).

Two of the delays were required for grey seals, and the third delay, for long-finned pilot whales. The delays for grey seals were on UXO clearance projects, while the delay for long-finned pilot whales was on a decommissioning project. On all three occasions, detonations were delayed for at least 20 minutes after the last sighting in the mitigation zone; on the decommissioning project, JNCC had recommended a delay of 30 minutes which was complied with.

In the case of one of the grey seals, the ADD had been active for 12 minutes when it appeared in the mitigation zone; it resurfaced 20 minutes later, still in the mitigation zone. The ADD continued to be active throughout until the seal had not been observed in the mitigation zone for 20 minutes, resulting in a total of 52 minutes of ADD activation, after which scare charges were used prior to the main detonation. The other grey seal appeared after the last in a sequence of scare charges had been detonated; the ADD was reactivated throughout the delay until it was clear to proceed with the main detonation.

3.3.7 Scare charges

Scare charges were only used on UXO clearance projects, where they were used before 50% of detonations overall. Six of the 16 UXO clearance projects where data were received used scare charges; for two of these projects, the Marine Licence and European Protected Species Licence mentioned using a soft start procedure, while two others included the use of scare charges in the MMMP or Method Statement. For one further project, the MMMP said that scare charges would be used where safe to do so, but they were deemed unsafe and therefore were not used.

The duration of scare charge use increased with the number of scare charges employed (Table 9). Three charges was the most common number used, with a mean duration of 17 minutes. The maximum duration of 60 minutes for three charges was due to an occasion where there was a misfire of the third charge thereby prolonging the overall duration; ignoring that occasion the maximum duration for three charges was 35 minutes.

Table 9. Duration of use of scare charges on UXO projects in relation to the number of charges (n = sample size).

Number of charges	Minimum duration (minutes)	Mean duration (minutes)	Maximum duration (minutes)	n
1	0	1	5	8
2	10	12	15	3
3	15	17	60	52
4	16	20	26	18
5	31	31	31	1

Scare charges were usually used in conjunction with ADDs, with the scare charges usually commencing shortly after ADDs were deactivated. On only seven occasions were scare charges used without ADDs beforehand, all on one project that did not use ADDs. The other five projects using scare charges also used ADDs.

For 70 of the 82 occasions (85%) when scare charges were used, the detonation was immediately after the last scare charge. However, for 9% of occasions there was more than 10 minutes between the last scare charge and the detonation (excluding one occasion where the detonation was delayed due to a grey seal in the mitigation zone), with the maximum delay being 43 minutes.

MMOs were always monitoring for marine mammals prior to the scare charges being initiated. On all but one occasion monitoring had been underway for at least 30 minutes before the first scare charge was detonated, with the exception being a search of just 17 minutes. On 88% of occasions, monitoring had been ongoing for at least an hour before the scare charges commenced.

There was one occasion when a grey seal was seen briefly at the edge of the mitigation zone just after the last scare charge had been detonated. The ADD was redeployed and the main detonation delayed until the seal had not been seen for 20 minutes.

3.3.8 Sequencing of charges

Ten of the 16 decommissioning projects had only one detonation. Where there were multiple detonations during a project, the maximum number of detonations was six with detonations usually being on separate days. There were only two occasions with two detonations on the same day and one occasion with three detonations on the same day. Of those decommissioning projects that had more than one detonation, where the NEQ was recorded it was the same for all detonations.

Ten of the 16 UXO clearance projects had more than one detonation; the maximum number (excluding misfires) being 55. For projects with multiple UXOs, most (63%) days had just one detonation while on 33% of days two detonations were achieved. More than two detonations per day were rare, with two days with three detonations and one day each with four and five detonations. Most second or subsequent detonations were either the same day as the previous detonation (33%) or the next day (40%), with 14% having an interval of two days and only 13% having an interval of three days or more.

On six of the ten UXO clearance projects with multiple detonations, the NEQ of the donor charge remained the same throughout, while on three projects it varied with no clear increase or decrease. On one project, the NEQ of the donor charge was not recorded. Of more significance was the NEQ of the UXO, but this was recorded less often, with six projects with multiple detonations not recording (or mostly not recording) the UXO NEQ (although for one project the first detonation was recorded as being of a large UXO with NEQ 240kg). Of the four projects with multiple detonations where the UXO NEQ was routinely recorded, for two projects the UXO NEQ varied throughout, for one project it remained the same, while on one project it decreased (there were two detonations, the first being a large UXO with NEQ 260kg and the second being a smaller UXO with NEQ 32kg).

3.3.9 Detonations at night or in poor conditions

There was one decommissioning project where there were only two detonations and both occurred at night, although PAM was used both times. There were no ADDs or scare charges on this project, so PAM was the only mitigation measure. The MMO report said that a licence had been granted on condition that the JNCC guidelines were followed and reported that operations were compliant with the licence and guidelines. No explanation was given regarding why the detonations took place at night, nor was there any indication that they had endeavoured to undertake them in daylight. There were no other occasions when detonations took place at night, although there was one detonation at dawn and one at dusk on UXO clearance projects. The detonation at dusk had an adequate duration visual search while the detonation at dawn had a five minute gap during the search whilst switching from PAM to visual monitoring (see Section 3.3.4).

There were no detonations recorded as taking place in poor visibility, although there were some detonations where weather information could not be obtained from Effort data. However, on some projects, there were detonations in moderate visibility where the ability to observe the full extent of the mitigation zone may have potentially been compromised. This happened on five occasions on decommissioning projects and 11 occasions on UXO clearance projects; PAM was used to supplement visual monitoring on four and ten occasions respectively.

There were only two occasions when detonations commenced in 'rough' seas and/or swell > 4m; once on a decommissioning project and once on a UXO clearance project. PAM was used to supplement visual monitoring in both cases. However, there were 45 occasions (32 on UXO clearance projects and 13 on decommissioning projects) where Effort records suggested that detonations took place in ‘choppy’ sea states (equivalent to sea states 4 and 5) and/or swell > 2m, including seven detonations in ‘choppy’ seas on two UXO projects where the MMMPs said that detonations would not start in sea state > 3. PAM was used to supplement the visual search on 38 of the 45 occasions when detonations commenced in these conditions. There were eight further occasions where plans for detonations proceeded in ‘choppy’ sea states and/or swell > 2m but there were misfires. Excluding misfires, 25% of detonations took place in poor or suboptimal sea conditions.

One MMMP for a UXO clearance project indicated that detonations would commence in poor conditions if needed. The plan said, “If MMOs are not able to observe the entirety of the mitigation zone, e.g. due to a poor sea state or visibility, a PAM system may be used to perform the pre-detonation search”. The same report identified the harbour porpoise as the species most likely to be encountered during the project, however there was no consideration that harbour porpoises would not be able to be detected throughout the entirety of the mitigation zone if using PAM instead of visual monitoring (this project used single dual role MMO / PAM operators). In the event, all detonations on this project had visual monitoring beforehand.

There were a few occasions when detonations were delayed due to poor conditions; on one UXO project, the MMO report noted that operations were delayed on three occasions due to poor “surface visibility” (it was unclear whether this referred to visibility or sea state).

3.3.10 Post-detonation search

An adequate duration post-detonation search was conducted more often on UXO projects than decommissioning projects (Table 10). There were six inadequate post-detonation searches on decommissioning projects and seven on UXO clearance projects. Although these numbers are low, for decommissioning projects this represents approximately one in five post-detonation searches. Most inadequate searches on decommissioning projects did not last for the required 15 minutes post detonation, but for two cases where detonations took place at night there was no search made. Compliance was higher on UXO projects, but where searches were inadequate this was always due to the search not being done at the correct time (five ended too soon but two started late); there were no occasions on UXO projects when there was no post-detonation search. There was one report from a UXO project that said that the licence required a visual search for 24 hours following the final detonation, but a search for the full 24 hours did not happen due to the weather conditions the following day.

Table 10. Percentage (and sample size) of adequate duration post-detonation searches.

Year	Decommissioning		UXO	
2010	0.0	(1)	-	
2011	50.0	(2)	100.0	(2)
2012	-		100.0	(1)
2013	-		62.5	(8)
2014	100.0	(1)	-	
2015	100.0	(1)	-	
2016	100.0	(3)	100.0	(36)
2017	90.0	(10)	87.5	(8)
2018	40.0	(5)	100.0	(2)
2019	-		94.3	(35)
2020	100.0	(6)	98.2	(55)
2021	-		100.0	(6)
Total	79.3	(29)	95.4	(153)

For most post-detonation searches (63.8%) no notes were made; however it is unclear whether this means there were no observable impacts in all cases. Observations were sometimes noted in MMO reports rather than in data; 55 of the 115 cases where no notes were made came from a project where MMO data were submitted without an accompanying MMO report, so potentially there could have been observations that were not available for examination.

Where impacts were noted, the most common was dead fish floating at the surface (or observed from a remotely operated vehicle) (Table 11). Sometimes there were only small numbers of dead fish, but for 13 of the 49 cases where dead fish were seen the number of fish exceeded 100. Fish species were not always identified although some records were of "very small" fish. Where numbers were given, unidentified small fish, identified small species or juveniles of other species accounted for 85% of the total. Where species were identified, these included whitebait (collective term for juvenile fish of a number of species), sprat, pollock, saithe, whiting, poor cod, pout, mackerel, garfish and John Dory. Photographic evidence was supplied confirming identification in some cases although in many cases the identification could not be confirmed. In one case, many of the dead fish were recorded as having eye trauma, with protruding eyes. Feeding birds were sometimes seen, usually in combination with dead fish. There were two occasions where dead crabs were seen (once from a remotely operated vehicle) and one occasion when two dead birds (both guillemots) were observed along with ≥ 300 dead sprat.

Table 11. Observations made during post-detonation searches.

Observations	Number of observations	Percentage of post-detonation searches
No notes made	115	63.8
No evidence of impacts	14	7.7
Dead fish	49	27.2
Dead birds	1	0.6
Dead crabs	2	1.1
Feeding birds	11	6.1

3.4 Response of marine mammals to explosives

3.4.1 Detection rates prior to and post detonations

No significant differences were found in detection rates of seals or cetaceans between the periods prior to and post detonations, although sample sizes were low (Table 12). Similarly, there were no significant differences in detection rates of grey seals or the combined groups of all seals or all cetaceans between the hours following detonations and other periods, although sample sizes were again low (Table 13).

Table 12. Marine mammal detection rates prior to and post detonations, tested using the Wilcoxon signed ranks test (T^+ = sum of ranks of pairs where detection rate prior to detonation exceeded detection rate post detonation; n = number of matched pairs; d.f. = 1).

Species	**Median detection rate per hour *(+ 1st and 3rd quartiles)***		**T^+**	**n**	**p-value**
	Prior to detonation	**Post detonation**			
All seals combined	*0.00* 0.00 *0.09*	*0.00* 0.06 *0.18*	8	6	> 0.500
All cetaceans combined	*0.00* 0.06 0.13	*0.00* 0.00 *0.06*	18	7	0.289

Table 13. Marine mammal detection rates in the hours following detonations compared to other times, tested using the Wilcoxon signed ranks test (T^+ = sum of ranks of pairs where detection rate at other times exceeded detection rate in the hours following detonations; n = number of matched pairs; d.f. = 1).

Species	**Median detection rate per hour *(+ 1st and 3rd quartiles)***		**T^+**	**n**	**p-value**
	In the hours following detonations	**All other times**			
All seals combined	*0.00* 0.00 *0.00*	*0.05* 0.09 *0.18*	33	9	0.125
Grey seal	*0.00* 0.00 *0.08*	*0.00* 0.05 *0.18*	12	6	0.422
All cetaceans combined	*0.00* 0.00 0.00	*0.02* 0.08 *0.23*	21	7	0.148

3.4.2 Closest distance of approach to the detonation site

Seals were not significantly further from the detonation site in the hours following detonations compared to other times (Figure 8, Table 14), although sample sizes were low.

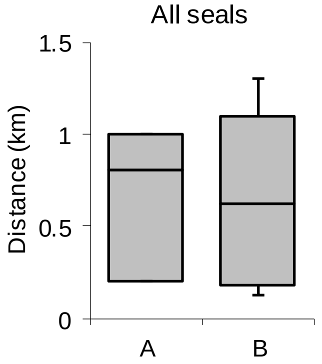


Figure 8. Box-and-whisker plots of closest distance of approach to the detonation site relative to activity (A = hours following detonations; B = all other times). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers.

Table 14. Closest distance of approach of marine mammals to the detonation site, tested using the Wilcoxon-Mann-Whitney test (W_x = sum of ranks of the smallest group; n = sample size; d.f. = 1).

Species	Median closest distance (metres)		W_x	n	p-value
	Hours following detonations	All other times			
All seals	800	625	17	11	0.461

3.4.3 Behaviour

Apart from normal swimming or surfacing, the most common behaviour recorded was travel away from the vessel, which was recorded ten times (six times for cetaceans and four times for seals). Travel away from the vessel was recorded both prior to and post detonations in both seals and cetaceans. Diving was recorded eight times (six times for seals and twice for cetaceans). All occasions when seals were recorded as diving occurred after detonations; diving in seals was not recorded before detonations, although there were only five sightings of seals at these times.

There was one occasion when a grey seal was seen while an ADD was active and another when scare charges were being detonated. The grey seal that was seen in the mitigation zone while an ADD (a Lofitech device) was active was recorded as “swimming away from the vessel with head turned backwards”. It initially surfaced in the mitigation zone 12 minutes after the ADD was first activated, then resurfaced in the same position 20 minutes later when the ADD was still active. ADD activation then continued for a further 20 minutes after the last detection of the seal before scare charge detonation commenced. A juvenile grey seal that briefly appeared in the mitigation zone just after the last in a sequence of scare charges had been detonated was recorded as milling at the surface with its head out of the water (the planned main detonation was delayed and an ADD was redeployed).

4 Discussion

4.1 Submission and quality of data

Submission of MMO reports and data for O&G decommissioning projects was poor; after allowing for those where mitigation was not required or it was known that explosives were not, or probably were not, used, only around half of the projects submitted a report and/or data. It is possible that some of the remaining projects where there were no submissions used methods other than explosives, but there is no evidence to suggest that was the case. A method of tracking decommissioning projects with a record of methods used would be beneficial.

Submission of MMO reports and data for UXO clearance projects was also below the level that would be expected, with almost a third of projects not submitting anything. Different regulators manage different UXO clearance projects depending on location, so there was no central repository. Ensuring that all reports and data are submitted to JNCC as well as the relevant regulator would improve collation of data and support future analysis.

Where data were submitted these were mostly usable for this analysis but still required corrections to be made. Some were in pdf format and had to be transcribed before corrections could be made and they could be imported into the database. Many of the errors pointed to a lack of care with data recording and a lack of checking. Mistakes such as entering data into the wrong columns and mixing up east and west in positions of longitude are easily avoidable if observers take care when entering data; and if such mistakes are made, it would be expected that they would be picked up prior to submission of data if checks were made. Combining source activities as 'variable' over a period rather than separating out records with different source activities on the Effort form indicates a lack of diligence. MMOs and PAM operators should ensure they record their data accurately with the level of detail required and should also make thorough checks of their data. Checks should include cross-referencing between forms to ensure that source activities recorded on Effort and Sighting forms match the activity that has been recorded on the Operations form. Where mismatches occur and the activity recorded on one form contradicts that recorded on another, it is difficult for anyone not involved in the project to determine which form held the correct record of activity and therefore be able to make corrections with confidence. The probability of being able to correct this is much greater for the mitigation personnel involved, particularly if they make such checks during the project when they may be able to check against records of activity held by the crew.

There is a need for recording forms designed specifically for explosives that would facilitate recording relevant information such as whether high-order or low-order methods are used, the NEQ (for both donor charge and UXO in the case of UXO clearance projects), and the timing of the use of ADDs and scare charges. Although these details were recorded by some MMOs and PAM operators, given that the current forms do not ask for this information there was inconsistency in how and where it was recorded. This is further discussed in Section 4.6 and recommended items for inclusion in recording forms are listed in Appendix 2.

For projects where no submissions were made, it is not known whether there was compliance with the JNCC guidelines or even whether there was any mitigation at all. Therefore, it should be borne in mind that the true level of compliance with the guidelines could be lower than that presented in this report.

4.2 Distribution of marine mammals

The distribution of marine mammal encounters during projects using explosives largely reflected survey effort, which varied both spatially and temporally. Given this variation in effort, caution should be exercised when interpreting distribution maps. Furthermore, the distribution of animals was potentially influenced by the activities. Nevertheless, observed differences in distribution between species mostly concurred with known distribution patterns.

Both grey and harbour seals were seen in coastal locations close to known haul-out and breeding sites but were also seen further offshore. However, grey seals were seen on the east coast of Scotland as well as in the southern North Sea, while harbour seals were only seen in the southern North Sea. Harbour seal abundance is stable or increasing along the English North Sea coast but has declined along the Scottish North Sea coast, while grey seal abundance has increased throughout the UK (Mitchell *et al.* 2018).

Minke whales were the cetacean species most frequently seen during explosives projects, being seen throughout the northern North Sea and also in deeper waters, which concurs with their known distribution (Reid *et al.* 2003; Hammond *et al.* 2013, 2021).

The harbour porpoise is one of the most abundant cetaceans in European Atlantic waters (Hammond *et al.* 2021). The harbour porpoise was found throughout the North Sea, reflecting its widespread distribution in UK waters (Reid *et al.* 2003; Hammond *et al.* 2013, 2021). There has been a southward shift in distribution of harbour porpoises in the North Sea (Hammond *et al.* 2021) and accordingly this species was seen in both the southern and northern North Sea.

Other species were only seen in low numbers, but the distribution of sightings again largely concurred with known distribution. Long-finned pilot whales are known to occur in deep waters to the north and west of Britain (Reid *et al.* 2003; Hammond *et al.* 2021), while killer whales are known to occupy more northern areas in both shelf and deep waters (Reid *et al.* 2003; Forney & Wade 2006). White-beaked dolphins are mainly encountered in shelf waters of the North Sea and west Scotland (there were no data from the west of Scotland) but also occasionally in deeper waters (Reid *et al.* 2003; Hammond *et al.* 2013, 2021). Bottlenose dolphins are known to be locally common on the north-east coast of Scotland (Reid *et al.* 2003; Hammond *et al.* 2013, 2021). The single humpback whale sighting occurred off the Firth of Forth, where there have been other sightings of humpback whales in recent years (O'Neil *et al.* 2019); sightings of humpback whales have also increased in other parts of the North Sea, with this species now being considered an annual visitor rather than a rare vagrant in the southern North Sea (Leopold *et al.* 2018).

4.3 Compliance with guidelines

4.3.1 Noise abatement

Noise abatement was not regularly practised during the explosives projects examined here. The only occasions when there was any attempt to reduce source levels, or the spread of noise were on a few UXO clearance projects in recent years. Bubble curtains were sometimes required for UXOs with a high NEQ on some projects in 2018 and 2019, and one project in 2021 used an alternative low-noise method rather than a high-order detonation.

Schmidtke *et al.* (2009) found that bubble curtains were effective at attenuating the shock wave with small charges, with a reduction up to 16 dB. For larger charges, the attenuation was less (approximately 4 dB) but they suggested that a larger radius for the bubble curtain would improve attenuation by suppressing the effect of the flow of displaced water. Koschinski (2011) noted that the efficiency of bubble curtains depends on their width and shape, air volume and bubble size but considered that they could substantially reduce the danger zones for marine organisms provided that their radius is large enough. Only one of the two projects using a bubble curtain reported its diameter, but with a diameter of 80m it was larger than the 22m diameter used by Schmidtke *et al.* (2009).

Although only one project used an alternative to high-order detonations, it is anticipated that alternative methods will be used more for future projects. DEFRA, together with other UK government departments and statutory advisors, issued a joint interim statement at the end of 2021 recommending the use of low noise alternatives to high-order detonations for UXO clearance whenever possible (DEFRA 2021). Such low-order methods include deflagration, where the explosive substance is consumed by burning rather than detonated, effected by a smaller donor charge than a conventional high-order detonation. The peak sound pressure level and sound exposure level are more than 20 dB lower for deflagration compared to a high-order detonation and the acoustic output depends only on the size of the shaped charge and not the size of the UXO (Cheong *et al.* 2020; Merchant & Robinson 2020; Robinson *et al.* 2020). Furthermore, the spread of toxins is potentially reduced with deflagration as the explosion is less violent and more localised (Cheong *et al.* 2020). However, not all ordnance may be suitable candidates for deflagration, particularly severely degraded items that cannot be identified, as the technique requires the donor charge to be placed correctly on the UXO which depends on correct identification (Cheong *et al.* 2020).

4.3.2 MMOs and PAM operators

The average number of personnel on the mitigation team was the same for both UXO and decommissioning projects. However, although UXO clearance projects more often used PAM in addition to visual monitoring and in one case had three dedicated MMOs on board, these projects more often had a single person for mitigation than decommissioning projects. UXO clearance projects sometimes had a single dual role MMO / PAM operator, whereas this did not happen on decommissioning projects. Having a single person performing both roles may not allow for sufficient breaks and could lead to fatigue; this practice should not continue as it is unrealistic to expect one person to cover both roles, even if the project is of short duration. Furthermore, monitoring is likely to be compromised by having one person performing both roles, due to having to choose between methods or alternate methods during the pre-detonation search. Using remote headphones to monitor acoustically whilst simultaneously monitoring visually is likely to compromise effectiveness of both methods, partly due to distraction of one method from the other, and partly due to the inability to monitor screens for PAM.

4.3.3 Use of PAM

PAM was used on all but one of the projects where it was a condition of the licence. It was used more often on UXO clearance projects than decommissioning projects, perhaps because of the larger NEQs involved with some UXOs.

The reason for the low number of acoustic detections is unclear. Reduced acoustic detection rates compared to visual detection rates have also been found with PAM used for mitigation on geophysical surveys (Stone 2023a). Less than one third of the time spent monitoring on site during explosives operations was acoustic, but even allowing for that the number of acoustic detections was very low. One report noted some noise on the received PAM signal, due mostly to the vessel thrusters, which could potentially have masked biological sounds. Most visual detections were of seals or minke whales, neither of which reliably vocalise underwater, therefore PAM is not an appropriate method of detection for these species (Herschel *et al.* 2013). Some harbour porpoises were detected visually, but there were no acoustic detections of porpoises. The high frequency clicks of harbour porpoise can be effectively detected acoustically but only within a range of around 400 m (Cucknell *et al.* 2016). This also means that PAM is limited in its ability to detect harbour porpoises within the full extent of a 1km radius mitigation zone.

One MMO report said that the JNCC guidelines seem slightly ambiguous and open to interpretation with reference to the requirement for PAM in conjunction with visual monitoring, but this should be clarified with JNCC's recent PAM guidance (JNCC 2023).

4.3.4 Pre-detonation search

Although most pre-detonation searches were of adequate duration, there were questions about the effectiveness of searches as sometimes the main vessel was towards the edge of or outside the mitigation zone. This would make the full extent of the mitigation zone (2km diameter) difficult to monitor, particularly for smaller species like the harbour porpoise and seals. In an attempt to overcome this, for some projects MMOs were located on a smaller vessel within the mitigation zone, but this also was not ideal due to the low height of eye (typically around 2m). This would make observations difficult, as was illustrated on the project where three of the four sightings were seen from the main vessel by personnel who were not carrying out a dedicated watch. Even if the smaller vessel was positioned in the centre of the mitigation zone, it is unlikely that small animals would be easily visible towards the outer portion of the zone from a platform with a low height of eye. One further problem with observing from a smaller vessel arose on one project, where searches commenced later than they should have, apparently due to the MMO having to take time out of monitoring to transfer between the main vessel and the smaller vessel less than one hour before the detonation.

The report from one project that had one MMO stationed on the main vessel and one on a smaller vessel recommended this approach for future projects. This would increase the search effectiveness and ability to cover the full extent of the mitigation zone. With this approach, it is important that there is effective communication between MMOs stationed on separate vessels.

Acoustic monitoring was often inadequate. Searches were sometimes not done, but even where there was a search it often was not long enough. On UXO clearance projects some acoustic searches were very short, with 20% being of less than 10 minutes duration. Such a short search would have severely compromised the ability to detect marine mammals acoustically. Even where searches were longer, many on both UXO clearance projects and decommissioning projects ended prematurely, possibly connected with the need to move to a safe standoff location prior to the detonation (which would require recovery of a vertically-deployed hydrophone cable) and/or recover the PAM cable prior to detonation to reduce the risk of damage to it (although the JNCC guidelines do note the potential need for sacrificial hydrophones). However, for most projects where PAM was required by licence there was full compliance with the requirement for acoustic searches, although licences were not available for inspection for some projects so this should be treated with caution. Notably one project where PAM was a licence condition did not use PAM.

4.3.5 Acoustic deterrent devices

Most explosives projects used ADDs, particularly UXO clearance projects where larger NEQs were involved. Varying durations were given for ADD deployment on UXO clearance projects, ranging from 15 minutes to no more than 80 minutes. Although it might be expected that duration would be related to the size of the UXO, as larger UXOs would be expected to have larger injury zones and therefore require marine mammals to be deterred over a greater distance, this did not appear to be the case.

Although there is no stated requirement in the current JNCC guidelines to monitor for marine mammals prior to activating an ADD, as most ADD deployments lasted less than one hour the pre-detonation search would have been underway at the time of deployment. For an ADD deployment of 30 minutes or less (as was the case for 69% of deployments) it would be expected that monitoring would have been ongoing for at least 30 minutes before the ADD was deployed. However, there were some occasions where a single MMO had to stop monitoring to deploy the ADD and this compromised the pre-detonation search in those cases.

Occasionally ADDs were active for a prolonged period; in one case over six hours. Once ADDs have been activated for long enough to deter animals to the required distance to avoid injury, there is no benefit to prolonging their use. Prolonged use could lead to unnecessary disturbance of marine mammals, or potentially to habituation.

On some occasions, there was a gap between the ADD being deactivated and the scare charge or detonation beginning, which potentially could result in a loss of the deterrent effect. Even with a gap of five minutes, a harbour porpoise could potentially travel 450m based on a conservative swim speed of $1.5ms^{-1}$ as used by Herschel *et al.* (2013), although a return may be unlikely within a short space of time. With a gap of 41 minutes (the maximum recorded), a porpoise could potentially swim a distance of 3.69km. With a longer gap between ADD deactivation and scare charges or detonations commencing, it is more likely that animals may start to return, although Thompson *et al.* (2020) found that the minimum time for a harbour porpoise to return to within 1km of playback of a Lofitech device was 133 minutes. However other species, where the deterrent effect is less, may return sooner.

4.3.6 Delays in operations

There was full compliance on the few occasions when delays were required due to the presence of marine mammals in the mitigation zone. Of the three delays required, two occurred when grey seals appeared in the mitigation zone following other mitigation measures, in one case while an ADD was active and in the other case just after the last in a series of scare charges. Both these instances highlight the importance of monitoring alongside other mitigation measures designed to deter animals, as not all animals may be deterred.

On both occasions when operations were delayed due to grey seals, ADDs were used to attempt to remove the seals from the mitigation zone, in one case by prolonging use of an already active ADD and in the other case by reactivating it. In the case where use of an already active ADD was prolonged, this did not seem effective as the seal resurfaced in the mitigation zone after 20 minutes.

4.3.7 Scare charges

The current JNCC explosives guidelines do not include a recommendation that scare charges should be used, yet these were a common mitigation measure on UXO clearance projects, sometimes featuring in MMMPs or in licences. Although the principle is similar to the soft start that is used on geophysical surveys and piling operations (JNCC 2010b, 2017), there is a lack of evidence regarding the effectiveness of scare charges for deterring animals prior to a larger detonation. Klima *et al.* (1988) found that small explosive charges were not always effective at moving bottlenose dolphins away from a detonation site and Continental Shelf Associates Inc. (2004) suggested that odontocetes may be attracted to fish killed by explosions and may thus be attracted rather than repelled by scare charges. As scare charges were almost always preceded by the use of ADDs, it is unclear whether they provided any additional benefit, although ADDs do not deter all animals (Kastelein *et al.* 2006; Dííaz Lóópez & Mariñño 2011; Harcourt *et al.* 2014; Harris *et al.* 2014; Pirotta *et al.* 2016; Mikkelsen *et al.* 2017; Gordon *et al.* 2019, Basran *et al.* 2020; Stone 2023c). Koschinski (2011) noted that the possible risks and benefits of small scare charges must be carefully balanced, regarding them as possibly beneficial for single detonations but bearing in mind that even small charges could be harmful to marine life at close ranges. Robinson *et al.* (2022) noted that the very short duration of scare charges might provide limited directional information and therefore limited deterrent effect on marine mammals, and cautioned that their use in mitigation would need to be justified considering the substantial additional impulsive noise they introduce to the environment.

If scare charges are used, it is important that there is monitoring beforehand. As scare charges were usually used for a period of around 15-30 minutes, the pre-detonation search would already be underway. Ideally monitoring should commence one hour prior to the scare charges commencing (as would be the case for the main detonation), which would require a longer overall search. Although this was often the case, there were some occasions where the search only commenced one hour (or occasionally less) before the main detonation resulting in a shorter period of monitoring prior to the scare charges commencing. As marine mammals could potentially suffer permanent threshold shift (PTS) at close range from scare charges, it is important that detonations of scare charges are delayed if a marine mammal is detected in the mitigation zone prior to their use, or suspended if a marine mammal enters the mitigation zone during a sequence of scare charges. Harbour porpoises could potentially suffer PTS at a range of 748m from a 50g scare charge (BOWL 2016).

If there is a benefit to using scare charges, then the main detonation should take place immediately after the scare charges without a gap in between where animals could potentially start to return to the vicinity. On 9% of occasions, there was a gap of more than 10 minutes between the scare charges ending and the main detonation; with a swim speed of 1.5ms^{-1} (Herschel *et al.* 2013) a harbour porpoise could potentially return 900m or more during these intervals.

4.3.8 Sequencing of charges

UXO clearance projects often have multiple UXOs to clear of varying kinds (e.g. ground mines, buoyant mines, bombs of varying sizes (250lb, 500lb and 1,000lb), naval projectiles and rockets). Although the JNCC guidelines recommend that charges are sequenced starting with smaller charges and leaving larger charges until last, there was apparently no attempt to do this and sometimes the first detonation was of a UXO with a high NEQ. None of the MMO reports gave any reasons for the order in which UXOs were detonated, although this is likely to be due to the size of UXO not being determined until immediately prior to clearance. Where there are multiple UXOs to be cleared on the same or next day, it would be preferable to have a progression of detonations of increasing NEQ, or at least to avoid starting with a UXO with a high NEQ.

4.3.9 Detonations at night or in poor conditions

Under the JNCC explosives guidelines, detonations should only commence during hours of daylight and in good visibility; the guidelines say that observers should be able to monitor the full extent of the mitigation zone. However, a later section in the guidelines discusses the use of PAM for monitoring when visual monitoring is ineffective (noted as periods of darkness or poor visibility or when the sea state is not conducive to visual mitigation), which does make the situation somewhat ambiguous. The pre-denotation search is defined as "a visual watch and, if required, acoustic monitoring", which implies that a visual search is always required. Most operators took a conservative approach and only commenced detonations in daylight with visual monitoring beforehand (sometimes supplemented with PAM), except for the project where both detonations commenced at night with PAM only. Given that PAM would be incapable of detecting harbour porpoises throughout the full extent of a 1km mitigation zone (Cucknell *et al.* 2016) and is not an appropriate method of detection for seals or minke whales (Herschel *et al.* 2013), effective monitoring cannot be conducted prior to detonations taking place at night. Although the guidelines do not explicitly define daylight, visual monitoring may also be compromised in low light conditions at dawn and dusk.

As well as not being able to monitor adequately prior to a detonation, undertaking detonations at night also means that a post-detonation search is impossible. Post-detonation searches would also be compromised at dawn and more so at dusk where light would be continuing to fade.

Although no detonations were recorded as taking place in poor visibility, one project had a MMMP where this would have been allowed, using PAM as a substitute for visual monitoring with no consideration of its effectiveness for harbour porpoises beyond a few hundred metres or for seals or minke whales. The plan was submitted to, and presumably approved by, the regulator. Regulators should ensure that MMMPs provide for effective monitoring in all conditions where detonations are proposed or place appropriate limitations on the conditions when detonations can take place.

For those detonations that took place in moderate visibility, it could not be ascertained from the data whether the full extent of the mitigation zone was visible. PAM was usually used to supplement visual monitoring in moderate visibility, but PAM would be unable to detect harbour porpoises throughout the full extent of the mitigation zone. In moderate visibility, monitoring the outer reaches of the mitigation zone could potentially be compromised both visually and acoustically. To ascertain whether there has been effective monitoring for future projects, the Marine Mammal Recording Forms could ask whether the full extent of the mitigation zone could be seen.

Visual monitoring is also compromised in higher sea states or swell (e.g. Northridge *et al.* 1995; Teilmann 2003; Hammond *et al.* 2013). The current guidelines do not address these conditions other than to recommend the use of PAM. Detonations in poor or suboptimal sea conditions were not uncommon. The same project that would have allowed PAM as a substitute for visual monitoring in conditions of poor visibility would also have allowed this in conditions of poor sea states. Whilst PAM may be a useful addition in such conditions, data from geophysical surveys have shown that detection rates from visual monitoring, while compromised, are higher than those from PAM in such conditions (Stone 2023a). Therefore, PAM should only be used as a supplement to, and not as a substitute for, visual monitoring during a pre-detonation search.

4.3.10 Post-detonation search

Although the number of occasions when there was not an adequate post-detonation search was low, the proportion of detonations this represented for decommissioning projects was unexpected, being one in five detonations. Other than the two detonations that took place at night, there was always a post-detonation search but it is unclear why it was sometimes too short, as no explanations were offered. Given that pre-detonation searches almost always lasted until the detonation, there is no obvious reason why the search could not have continued for the required 15 minutes afterwards.

Reporting of the results of post-detonation searches was poor. It is important that nil results (i.e. no observable impacts) are reported as well as those where mortalities are evident. Reporting could be improved by requesting observations to be recorded on the Marine Mammal Recording Forms.

Where results of post-detonation searches were reported, there were often records of dead fish. Lethal effects of underwater explosions on fish are well known (e.g. Klima *et al.* 1988; dos Santos *et al.* 2010), with small fish, species with swim bladders and deep-bodied species being more susceptible to death or injury although most fish species are at risk of being killed at very close range (Continental Shelf Associates Inc. 2004). In the current study, a range of fish species were observed to suffer mortality, but small fish accounted for the vast majority; Gitschlag *et al.* (2000), studying explosive removal of platforms in the Gulf of Mexico, also found that mortality was greatest for small fish. Although numbers of dead fish observed in the present study were often small, on some occasions over 100 dead fish were observed. However, actual numbers may have been higher; Gitschlag *et al.* (2000) found that generally more fish sank than floated following detonations (up to 97% sank in some cases) and suggested that total actual mortality may be much greater than that observed at the surface.

Other species, including crabs and birds (guillemots) were observed to suffer mortality on some occasions. Invertebrates, including crustaceans, have been found to be relatively insensitive to explosions, probably due to the absence of air cavities (Young 1991; Keevin & Hempen 1997). Bird mortalities have been recorded following underwater explosions, with damage to lungs, liver and kidneys being recorded during necropsies (Yelverton *et al.* 1973; Danil & St. Leger 2011). Yelverton *et al.* (1973) found that diving birds were more susceptible to injury, while those at the surface were relatively unaffected as the vulnerable organs were at least partially above the water line. Potentially the two dead guillemots observed could have been underwater at the time of the detonation.

4.4 Response of marine mammals to explosives

The low number of sightings / acoustic detections limited the ability to examine the response of marine mammals to explosives, particularly for individual species. Where data were able to be analysed, sample sizes were low, so the results should be treated with caution. There was no evidence of avoidance or displacement of marine mammals following detonations, either in the hours following the detonations or over a longer period. However, this does not necessarily mean there were no impacts, as effects are not always immediately apparent. For example, Todd *et al.* (1996) found that humpback whales showed little behavioural reaction to explosions but increased entrapment rate in nets subsequently may have indicated long-term effects of exposure to sound.

Although no effects of detonations were apparent in the present study, other studies have found negative impacts of underwater explosions on marine mammals. In California, three or possibly four long-beaked common dolphins died during an underwater detonation (Danil & St. Leger 2011). Following UXO clearance in German waters, 24 harbour porpoises were found dead along the coastline; 10 with evidence of blast injury (microfractures of the malleus, dislocation of middle ear bones, bleeding, and haemorrhages in the melon, lower jaw and peribullar acoustic fat) (Siebert *et al.* 2022). In 2011, a mass stranding of 39 long-finned pilot whales (from a pod of approximately 70) in the Kyle of Durness, resulting in the death of 19 animals, was thought to have possibly been caused by acoustic impairment or a behavioural response to a series of underwater explosions conducted during munitions clearance in the vicinity during the previous 24 hour period, although navigational error could not be ruled out as a possible cause (Brownlow *et al.* 2015). Smaller animals are more vulnerable to injury from underwater explosions than larger animals (Young 1991; Ketten 2006), with thresholds for the onset of mortality being proportional to the cube root of the body mass (US Navy 2015). Nevertheless, larger species have also sometimes suffered mortality following detonations; blast injuries were found in two humpback whales that died following an underwater explosion in Newfoundland (Ketten *et al.* 1993).

Sublethal effects have also been found following underwater explosions. Sundermeyer *et al.* (2012) found that explosive detonations led to a prolonged absence of harbour porpoises in the German Baltic Sea, with porpoises avoiding the site over a range of at least 10km for 12 hours after detonations. Lammers *et al.* (2017) found that acoustic activity of dolphins (presumed mostly bottlenose dolphins) off the coast of Virginia was lower during the hours and days following detonations, suggesting that animals left the area and/or reduced their signalling, with the apparent radius of response being between 3km and 6km. Koschinski (2011) noted that sublethal blast effects may contribute to increased mortality by predation, while sublethal auditory effects can affect the fitness of affected marine animals because hearing is vital for their behaviour and ecology.

Given the difficulties of observing impacts that may not be readily apparent and could occur over some range, some studies have used modelling to estimate impacts of the use of explosives on marine mammal populations, particularly the harbour porpoise. As a very high frequency cetacean, the harbour porpoise is more vulnerable to suffering auditory impairment than other marine mammal species in UK waters as a result of exposure to underwater noise (Southall *et al.* 2019). Von Benda-Beckmann *et al.* (2015) estimated that in a one year period, UXO clearance on the Dutch Continental Shelf very likely caused 1,280, and possibly up to 5,450, permanent hearing loss events in harbour porpoises, with some animals potentially exposed multiple times. Distances at which there was a risk of permanent hearing loss were in the order of one to several kilometres, and possibly further for larger explosions. Aarts *et al.* (2016), also modelling the impact of UXO clearance on harbour porpoises on the Dutch Continental Shelf, suggested that underwater explosions may impact a substantial part of the North Sea harbour porpoise population and that the number of animals affected may depend on animal movement. They demonstrated that more individuals would receive PTS and temporary threshold shift (TTS) if porpoises were free roaming; although the increase in numbers suffering PTS would be small, there would be a substantial increase in the numbers suffering TTS, with 10% of the North Sea population affected. Conversely, if porpoises remained in a local area fewer animals would receive PTS and TTS but more individuals would be subjected to repeated exposures. Given that most detonations in UK projects take place on separate days, movement of animals is an important consideration as new animals may move into an area in the period between detonations. For projects with multiple detonations, impact assessments that rely on density estimates to assess the number of animals impacted without allowing for movement of animals may underestimate the number of animals, and therefore the proportion of the population, impacted.

ADDs are audible to marine mammals at considerable distances (Kastelein *et al.* 2010). The Aquamark 210 device, used during two decommissioning projects, has been shown to deter bottlenose dolphins (Brotons *et al.* 2008). The Lofitech Seal Scarer, which was used more commonly on both decommissioning and UXO clearance projects, has been shown to deter harbour porpoises (Brandt *et al.* 2012a, 2012b, 2013; Dähne *et al.* 2017; Rose *et al.* 2019; Thompson *et al.* 2020; Graham *et al.* 2023) although the extent of the response has been found to vary. Even where avoidance has been reported, the response was not universal, with some harbour porpoises approaching close to the ADD (Brandt *et al.* 2012a, 2012b, 2013). Graham et al. (2023) found a strong directional response of harbour porpoises away from a Lofitech ADD used prior to pile driving, with evasive responses up to 7km away, but even then there were a few detections heading towards the source. The Lofitech device has also been shown to deter harbour seals, although responses observed did not always result in substantial movements away from the source, especially for seals that were travelling at the time of the exposures (Gordon *et al.* 2019). Mikkelsen *et al.* (2017), testing a sound simulating a Lofitech ADD but at lower source levels, found that harbour seals were seen more often and closer to the sound source when active compared to control periods and suggested that the sound could elicit curiosity rather than fear in seals. In the present study, one grey seal appeared in the mitigation zone while a Lofitech ADD was active and, although it was recorded as swimming away from the vessel, it resurfaced in the mitigation zone after 20 minutes. Grey seals have been found to be more persistent at remaining in an area with salmon nets during ADD use than harbour seals (Harris *et al.* 2014) and anecdotal reports from fish farms also suggest that grey seals are not deterred by ADDs as effectively as harbour seals (Sparling *et al.* 2015). ADDs used during pile driving operations in UK waters have been found to be not completely effective at deterring marine mammals, particularly seals, with one harbour seal trying to climb a monopile whilst remaining in the mitigation zone for a prolonged period during ADD activation (Stone 2023c).

Given the low number of sightings overall, it is impossible to assess the effectiveness of scare charges. The presence of a grey seal in the mitigation zone following a sequence of scare charges concurs with the findings of Klima *et al.* (1988), who found that small explosive charges were not always effective at moving bottlenose dolphins away from a detonation site. However, there was no evidence that marine mammals were attracted to feed on fish killed by scare charges, as had been suggested by Continental Shelf Associates Inc. (2004).

4.5 Considerations for future revisions to the guidelines

Since the current version of the JNCC explosives guidelines was published in 2010, there has been an increase in the use of explosives in the marine environment, particularly in recent years with the increasing need for UXO clearance prior to construction of offshore wind farms. As the guidelines were not written with UXO clearance in mind, there is a need for them to be revised in line with current best practice.

Noise abatement does not currently feature in the explosives guidelines, but a requirement to consider ways to reduce the level of noise should be included. Merchant and Robinson (2020) considered that it is feasible to use noise abatement technologies at all locations where offshore wind farms are proposed in UK waters, with techniques suitable for UXO clearance including bubble curtains and low-order methods such as deflagration. Inclusion of low-order methods in the guidelines would align with the joint interim statement issued in 2021 (DEFRA 2021).

The current guidelines do not address the number of mitigation personnel that are needed. There should be a requirement to ensure that enough personnel are present to provide effective monitoring, bearing in mind the potential need to have MMOs on more than one platform to cover the full extent of the mitigation zone. Having a single person acting as both MMO and PAM operator should not be permitted as the requirement to commence detonations in daylight and good visibility means that PAM would only ever be a supplement to visual monitoring, thus requiring at least two people to use both methods simultaneously.

Operators should be required to optimise the effectiveness of monitoring, both visual and acoustic. The position of the observation platform relative to the mitigation zone and the platform height of eye can both influence an observer's ability to monitor the full extent of the mitigation zone. If this is compromised in any way when using a single platform (e.g. when positioned at a stand-off location or on a vessel with low height of eye) the guidelines should recommend that two MMOs monitor simultaneously from separate platforms. Similarly, there should be consideration of the effectiveness of acoustic monitoring, particularly for harbour porpoises; more than one PAM array may be needed to detect porpoises throughout the full extent of the mitigation zone. As many acoustic searches were of inadequate duration the guidelines should also recommend that PAM deployment methods allow for pre-detonation searches for the full hour prior to detonation without terminating prematurely.

Some further revisions are needed in relation to PAM. As the guidelines say that explosive detonations should only commence during the hours of daylight and good visibility, reference to using PAM during darkness or poor visibility should be removed to avoid confusion. For decisions regarding delays for marine mammals detected acoustically where range is not able to be determined, there should be a precautionary approach. The guidelines should refer to JNCC's PAM guidance (JNCC 2023) to assist in determining cases where a delay would be required but bearing in mind that the examples given therein refer to the 500m mitigation zone typically used for geophysical surveys and pile driving, so there may need to be a greater level of caution when using a 1km mitigation zone for explosives.

The requirement to commence detonations only in daylight and good visibility could be more specific, for example there could be a requirement that all monitoring (pre- and post-detonation) should be completed between sunrise and sunset. For visibility, as a minimum the full extent of the mitigation zone should be able to be clearly seen from the observation position. Due to the difficulty of detecting marine mammals in poor or suboptimal sea conditions, particularly over a mitigation zone with a 1km radius (i.e. 2km diameter), detonations should be restricted to good sea conditions, with specific definitions of sea state and swell height provided (e.g. sea state ≤ 3 and swell ≤ 2m).

There have been some concerns about the use of ADDs, regarding the potential for auditory impairment (Coram *et al.* 2014; Schaffeld *et al.* 2019; Findlay *et al.* 2021, 2022; Todd *et al.* 2021), the risk of separation of mother-calf pairs (Brandt *et al.* 2013; Coram *et al.* 2014) and the level of far-field disturbance (Thompson *et al.* 2020). McGarry *et al.* (2020), reviewing evidence for the application of ADDs for marine mammal mitigation, concluded that the risk of injury (PTS) was low, but noted that it was possible that TTS could occur at short range for some devices. Schaffeld *et al.* (2019) found that TTS in harbour porpoises following a single exposure to an ADD at source levels typical of the Lofitech device could be expected up to 211m away in deep water and up to 5.9km away in shallow water. There have been suggestions that there should be a soft start of ADDs, to reduce the risk of TTS (Schaffeld *et al.* 2019) and to avoid causing panic reactions that could lead to separation of mother-calf pairs (Brandt *et al.* 2013). There have also been suggestions that source levels of ADDs should be optimised to achieve the desired deterrence whilst minimising the risk of TTS and broad-scale disturbance (Schaffeld *et al.* 2019; Thompson *et al.* 2020). However, many ADDs do not have the facility to vary source levels, which would also preclude a soft start. Nevertheless, to reduce the risk of TTS and panic reactions there should be consideration of source levels of available devices for any proposed ADD use. For the same reasons there should be consideration as to whether the guidelines should require a delay in ADD activation if marine mammals are in the mitigation zone, just as there would be for detonations (i.e. the ADD would not be activated until 20 minutes after the last detection of a marine mammal in the mitigation zone). This would also require an adequate period of monitoring prior to ADD activation. Correspondingly, there should be consideration as to whether it is appropriate to use ADDs to attempt to drive away animals that have appeared in the mitigation zone causing a delay in operations, or whether ADD use should be withheld until animals have left of their own accord. There also needs to be guidance about what to do if a marine mammal approaches during ADD use. If an animal remains undeterred within the mitigation zone during ADD use, the guidelines should require that the ADD is deactivated and operations delayed; once monitoring confirms that there have been no marine mammals in the mitigation zone for 20 minutes the ADD may be reactivated prior to proceeding with the detonation. The guidelines should also recommend that there is no gap between the end of ADD activation and commencement of detonations (including scare charges if used), to avoid the potential for animals returning.

There was little consistency amongst projects with regards to the duration of ADD use, even allowing for variations in the size of explosive. Currently the guidelines say that ADDs should be switched on for a pre-determined number of emissions during the pre-detonation search and switched off immediately once detonations commence. Further guidance could be given on determination of an appropriate duration, that could be used in Environmental Impact Assessments and MMMPs. To avoid unnecessary noise and far-field behavioural disturbance, ADDs should only be active for as long as required to deter an animal to a distance where it would no longer be at risk of injury. The duration of ADD deployment should be therefore determined on a case-by-case basis depending on the predicted injury zone (based on the largest explosive device in a project and the most vulnerable species) and typical swimming speeds. If predicted injury zones vary widely in a project due to different size explosives (e.g. on some UXO clearance projects), ADD durations may need to vary accordingly. The guidelines should also recommend that additional personnel are used to deploy the ADD, where this is necessary to avoid interrupting the pre-detonation search.

There should also be consideration of cumulative effects on marine mammals. If ADDs are proposed to deter animals on a project, there should be consideration of other activities that may also be using ADDs, to avoid animals being excluded from large areas.

Given the lack of evidence regarding the effectiveness of scare charges, there should be caution about including this as a standard mitigation measure in the guidelines. However, some guidance on the use of scare charges may be beneficial for projects where licences might require it. Such guidance might include monitoring for at least 60 minutes prior to the use of scare charges, delaying detonating them until 20 minutes after the last detection of a marine mammal in the mitigation zone, continued monitoring during their use, stopping all further charges if a marine mammal enters the mitigation zone during a sequence of charges, and proceeding with the main detonation immediately after the last scare charge providing the mitigation zone remains clear of marine mammals.

The guidelines say that any unusual observations during the post-detonation search should be noted in the report, but it is equally important to note if there was nothing unusual apparent. Post-detonation search reporting could be improved by including it on the Marine Mammal Recording Forms.

Given the number of projects where MMO reports and data were missing, it is recommended that the guidelines (and consent / licence conditions) require that these are submitted to JNCC as well as to the relevant regulator. This would enable a timely review of projects. Copies of licences and any MMMPs agreed with the regulator should be submitted alongside MMO reports so that they are available for consideration when assessing compliance. The guidelines should also recommend that MMOs and PAM operators make a thorough check of their data prior to submission, including cross-referencing between forms.

4.6 Considerations for future revisions to the recording forms

The existing Marine Mammal Recording Forms are designed primarily for geophysical surveys. Although they can be used for other activities such as the use of explosives, there are some columns that are not relevant and other information that would be relevant is omitted. Separate forms should be designed for explosives; a list of recommended items to be included on the forms is listed in Appendix 2.

Information specific to geophysical surveys on the Cover Page should be replaced with information relevant to the use of explosives (e.g. type of source (high-order explosives, deflagration, etc.), and details of any ADDs used (type, number and frequency).

The Operations form should have the facility to record the particulars of mitigation for each detonation, including the use of bubble curtains, times of ADD use and scare charges if used (times, number, minimum and maximum NEQs). Instead of asking whether it was day or night prior to operations, which might imply that night-time detonations are acceptable, the form should ask for confirmation that all monitoring and detonations were conducted in daylight. The form could also ask for confirmation that the full extent of the mitigation zone could be clearly seen. Details of the detonation should also be included: type of explosive, NEQ (both donor charge and UXO in the case of UXO clearance), seabed depth, whether the charge was downhole (and if so, downhole depth), and whether the detonation was successful or a misfire. The source (e.g. high-order detonation, deflagration, etc.) should be recorded for each activity as some projects may use more than one method; although both would be listed on the Cover Page, there is a need to distinguish which method was used on each occasion. Details of the post-detonation search should also be included on the Operations form, both the times of the search and any observations (including nothing seen where applicable).

Source activity on the Effort form and the record of explosive activity when animals are first and last detected on the Sighting form should include ADD, scare charges and misfires as options.

In the projects examined here, MMOs recorded sightings of animals that were seen whilst away from the project location, sometimes seen incidentally but sometimes during monitoring recorded on the Effort form. It is important to be able to distinguish Effort and Sightings on- and off-site when analysing the response of marine mammals to explosives. It is recommended that both the Effort and Sighting forms have the facility to record whether the vessel was on site or in transit.

5 Conclusions

This is the first analysis of MMO / PAM data from projects using explosives in UK waters. It was limited by the lack of available data, particularly the low number of detections of marine mammals, which restricted the analysis of responses of marine mammals to detonations. Although no responses to the activities were found, sample sizes were only sufficient for statistical analysis in a few cases and even then, sample sizes were low so the results should be treated with caution.

The level of compliance with the JNCC explosives guidelines could be assessed for those projects that submitted data, however as MMO reports and data were missing from approximately one half of decommissioning projects and one third of UXO clearance projects, the true level of compliance is unknown. Nevertheless, information could be gained to support recommendations for best practice.

Although in general compliance with the JNCC guidelines was good, there were some areas where mitigation could be improved. While compliance with the requirement for a pre-detonation search was generally good, monitoring could be improved by having two MMOs at different stations, to provide effective coverage of the full extent of the mitigation zone. Similarly, PAM deployment options need to allow for coverage of both the full extent of the mitigation zone and the full duration of the pre-detonation search. A single person was provided for monitoring on approximately half of the projects examined; engaging more personnel would allow these improvements to be made and increase the effectiveness of monitoring.

ADDs were a common mitigation measure, used on two-thirds of projects. However, the duration that they were active for varied and did not correspond to the size of explosive. Where the duration was specified in the licence, it was exceeded on almost half of occasions. There needs to be a more consistent approach to the use of ADDs, with the duration tailored in accordance with the predicted injury zone and a common approach to monitoring beforehand and procedures should a marine mammal be detected in the mitigation zone prior to or during ADD use.

Scare charges were used less often than ADDs, and only on UXO clearance projects. They were usually used following deployment of an ADD and it was unclear whether there was any additional benefit from using scare charges in addition to ADDs. However, the presence of grey seals on occasion demonstrated that neither ADDs nor scare charges are completely effective at deterring marine mammals, reinforcing the need for detonations to be conducted in good observation conditions with effective monitoring beforehand.

Detonations were delayed on the few occasions when this was required due to the presence of marine mammals in the mitigation zone, but sometimes ADDs were used to attempt to drive the animals away. Whilst ADDs can be a useful tool to try to prevent animals from entering the mitigation zone and may be particularly useful to deter animals beyond the range of detection by MMOs and PAM where predicted injury zones are large, whether they should be used to drive away animals detected in close proximity (rather than waiting for the animals to leave of their own accord) should be subject to question.

Noise abatement, whether by using bubble curtains or alternatives to high-order detonations, was practised on only a few projects. It is recommended that noise abatement is considered as a primary mitigation measure in future projects.

In the light of the results of this analysis, some recommendations for changes to the JNCC guidelines for explosives are made. These include: a greater emphasis on noise abatement (e.g. bubble curtains, low-order UXO clearance methods); ensuring there are sufficient numbers of mitigation personnel; consideration of the need for two observation platforms and/or PAM arrays; strengthening the requirement to commence detonations in daylight and good visibility, with more specific criteria including ensuring that pre- and post-detonation monitoring is completed in daylight; restricting detonations to good sea conditions; more guidance on the use of ADDs; caution and guidance on the use of scare charges; requiring that reports and data are submitted to JNCC as well as the relevant regulator; and recommending that MMOs and PAM operators perform thorough checks of their data. Proposals for Marine Mammal Recording Forms specific to explosives operations are also made.

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Appendix 1 - Species maps

On all maps the short, dashed line = 200m isobath; the long dashed line = 1,000m isobath. Maps show the number of individuals per licensing block (10' latitude x 12' longitude).

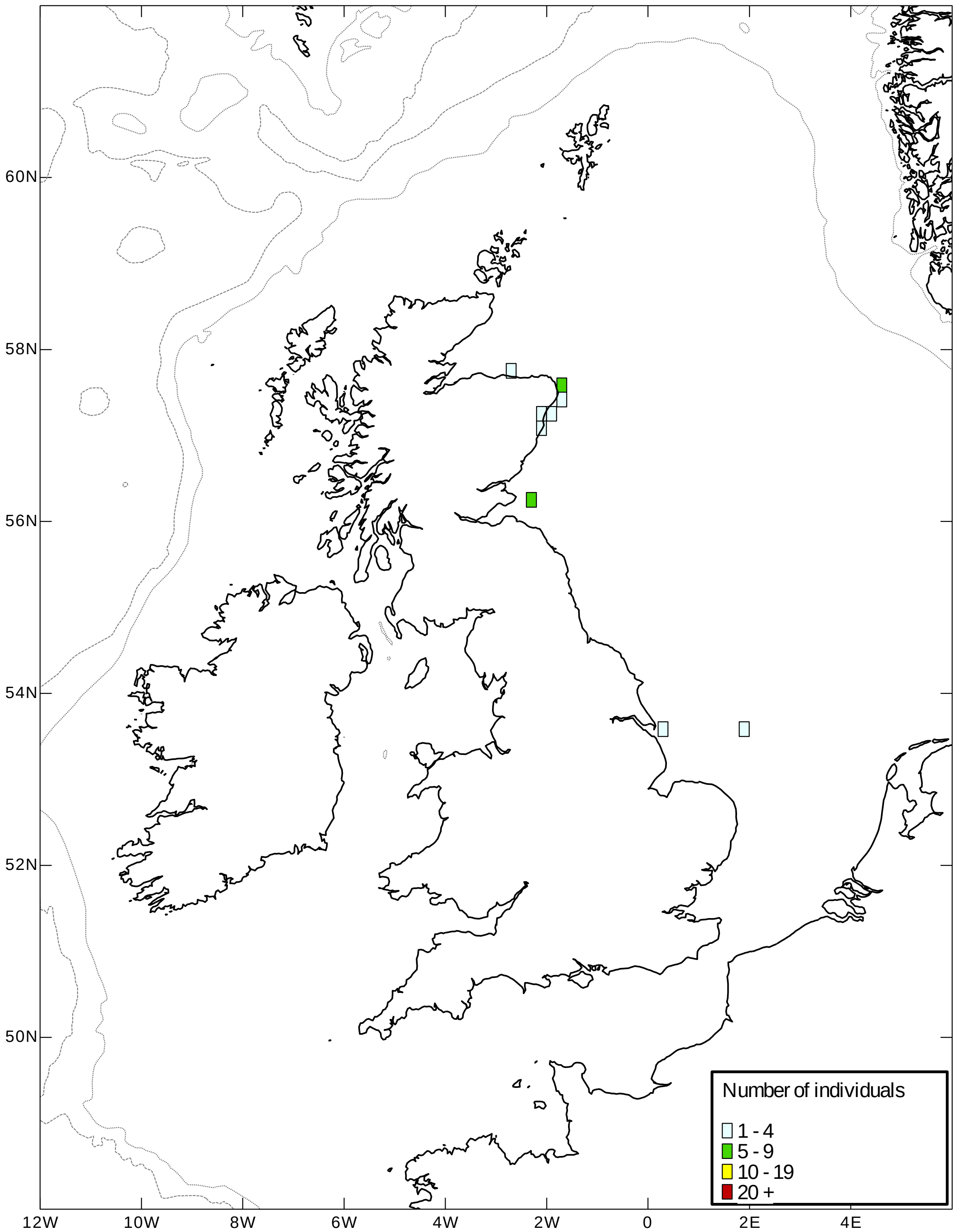

Figure 9. Grey seals encountered during projects using explosives, 2010-2021.

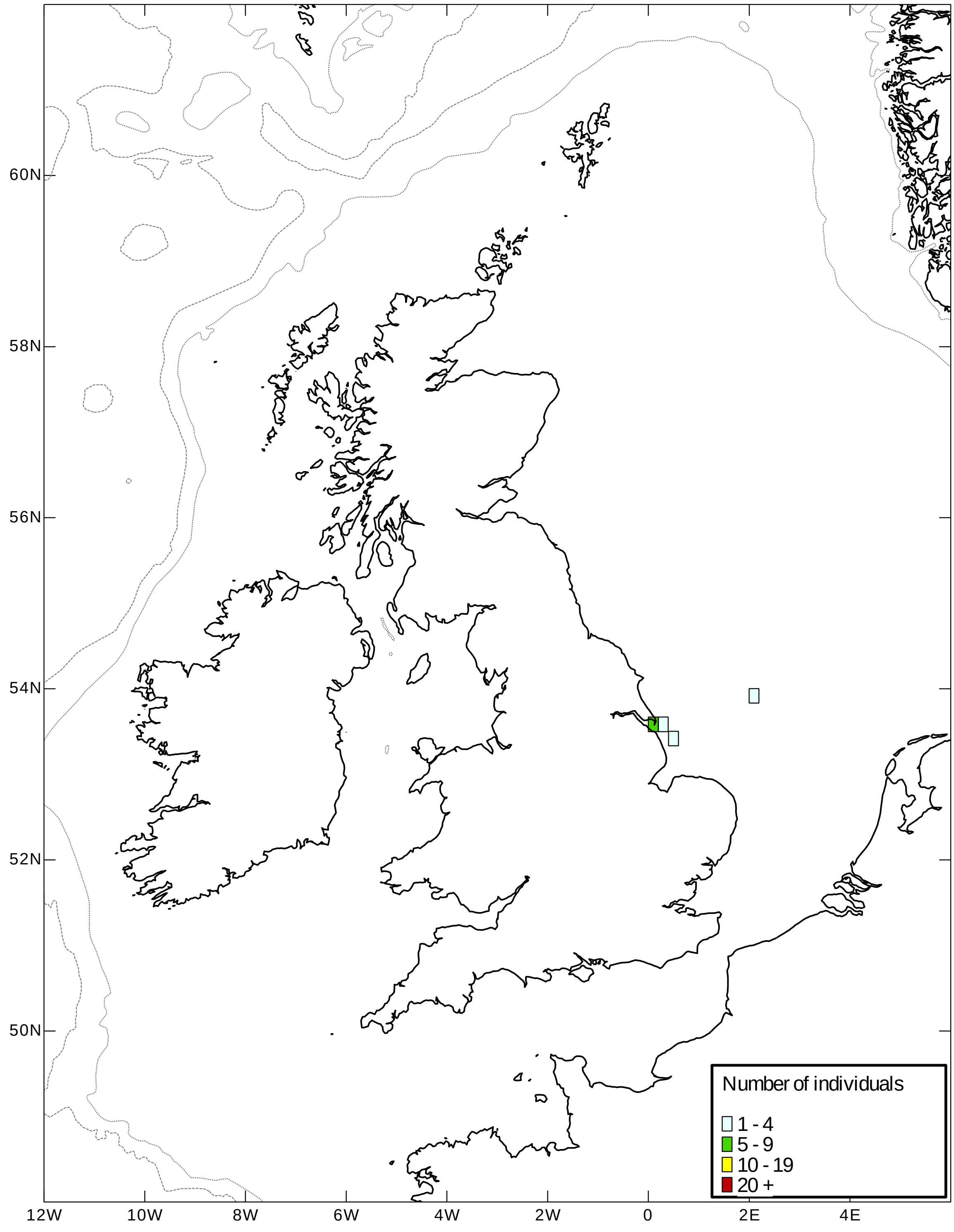

Figure 10. Harbour seals encountered during projects using explosives, 2010-2021.

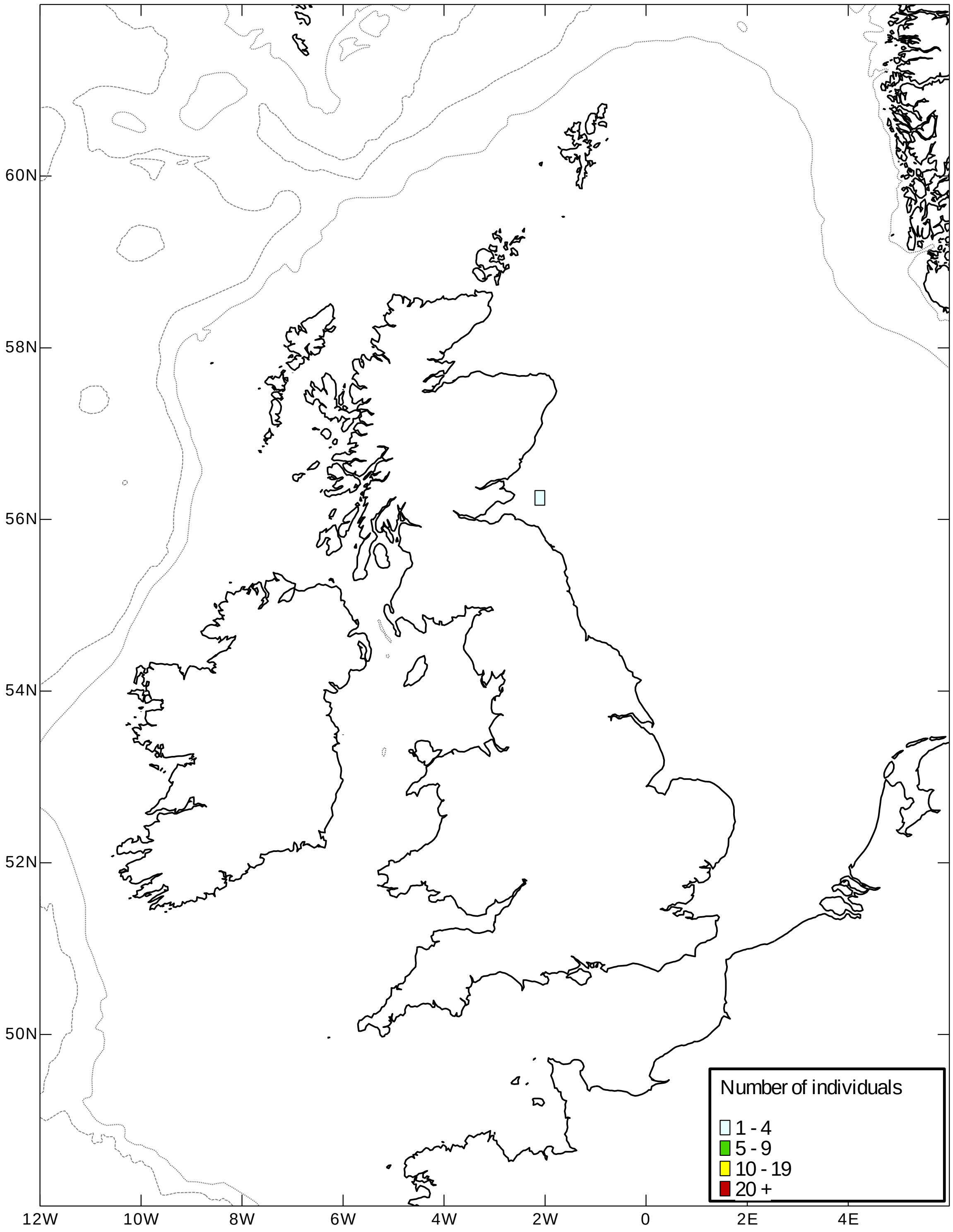

Figure 11. Humpback whales encountered during projects using explosives, 2010-2021.

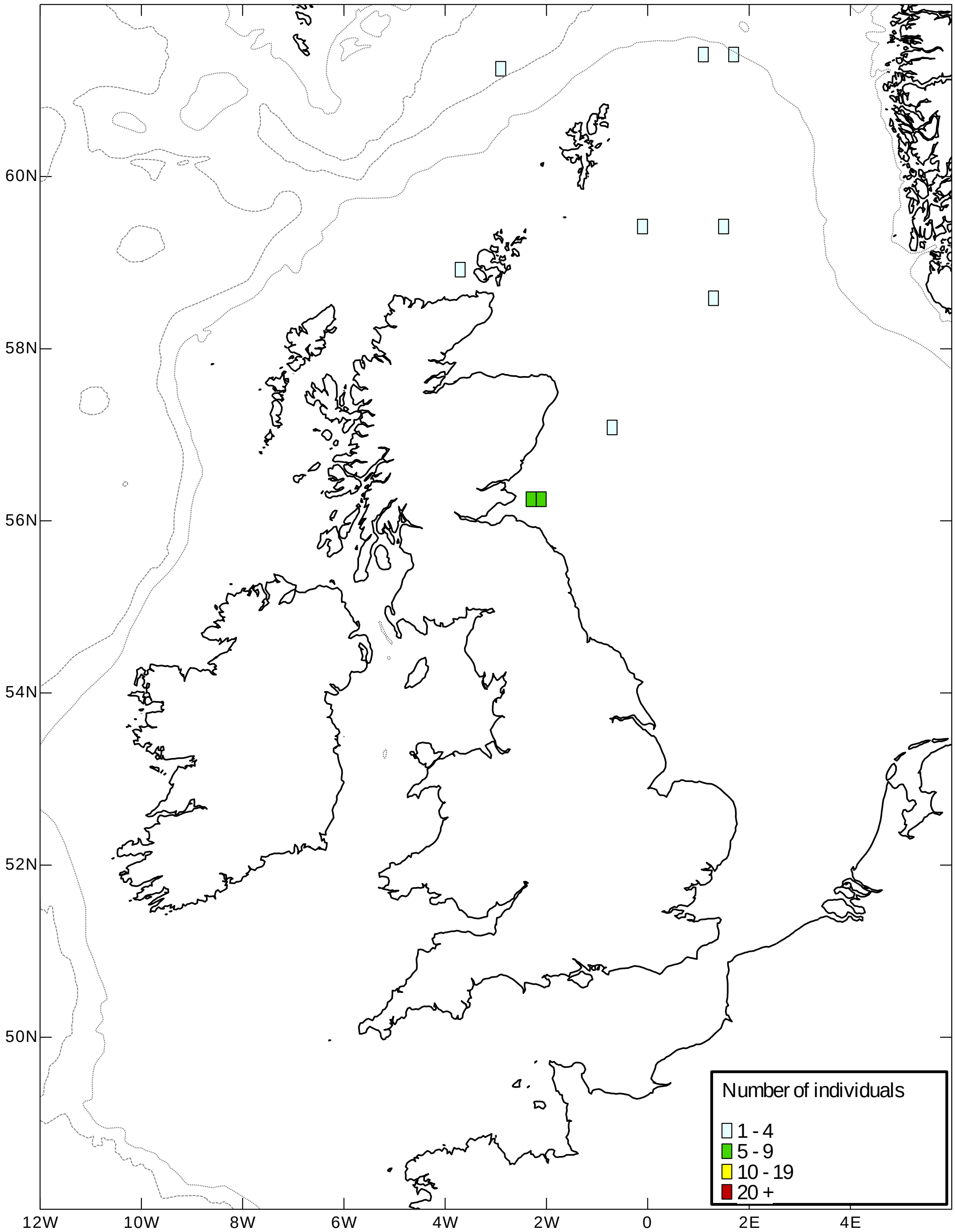

Figure 12. Minke whales encountered during projects using explosives, 2010-2021.

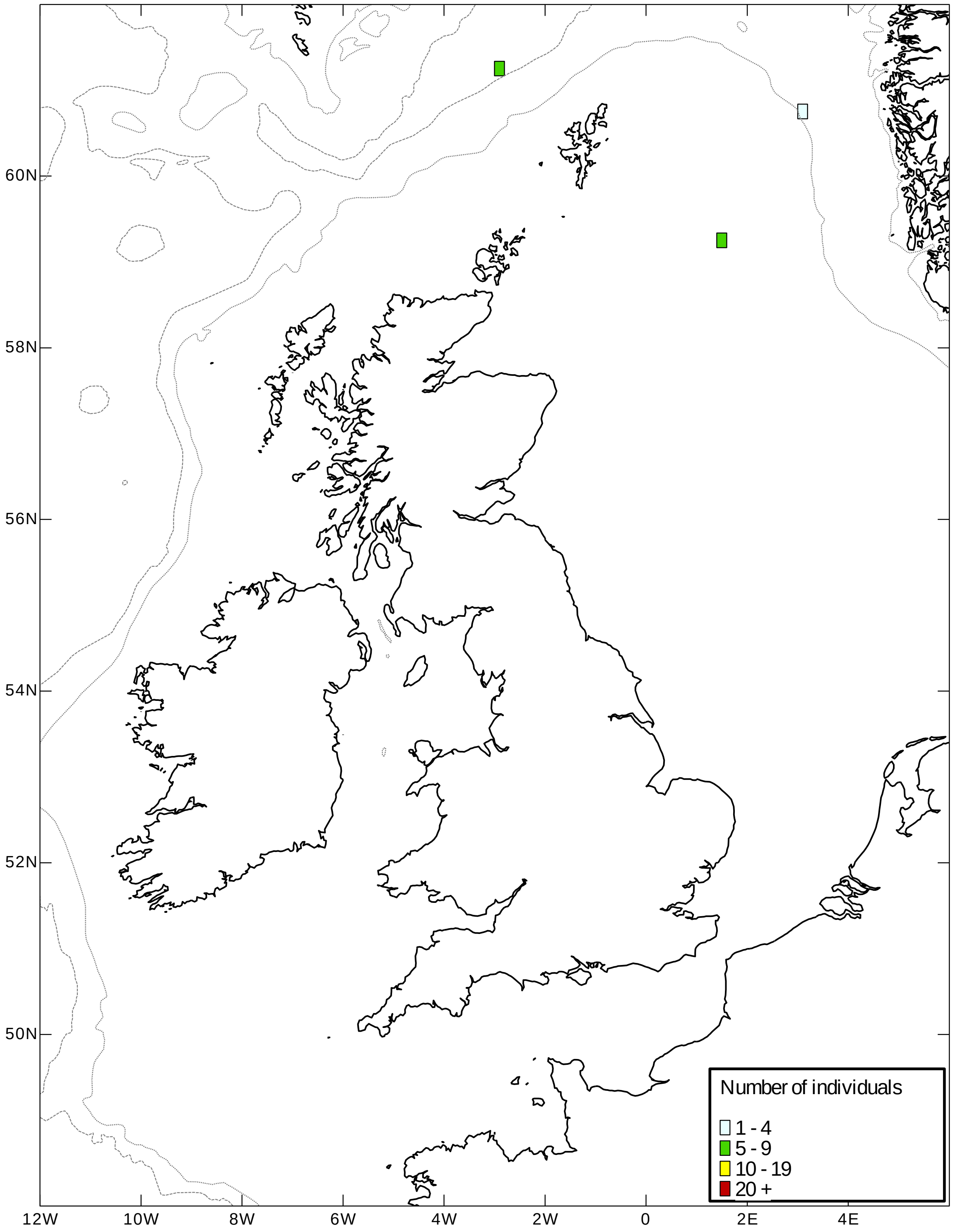

Figure 13. Long-finned pilot whales encountered during projects using explosives, 2010-2021.

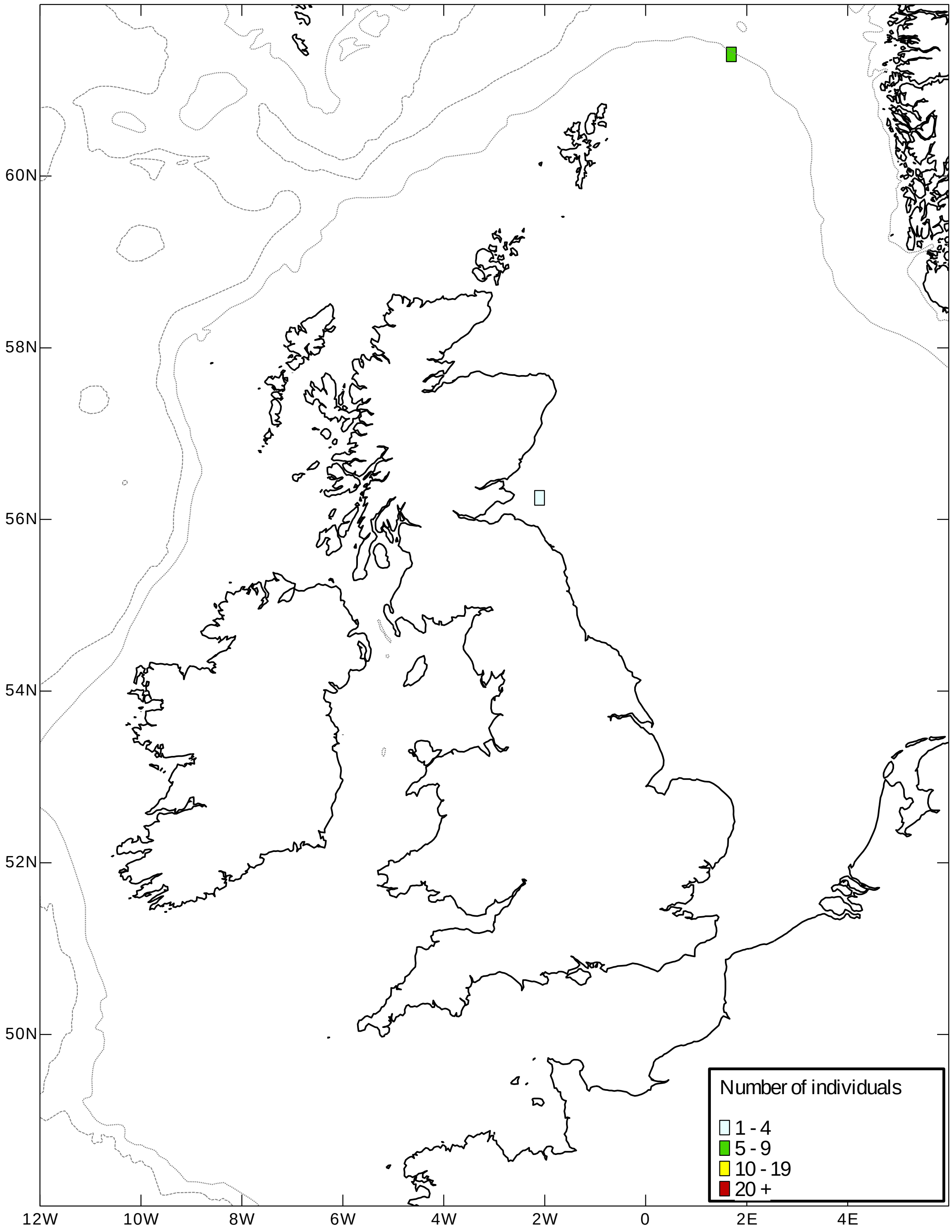

Figure 14. Killer whales encountered during projects using explosives, 2010-2021.

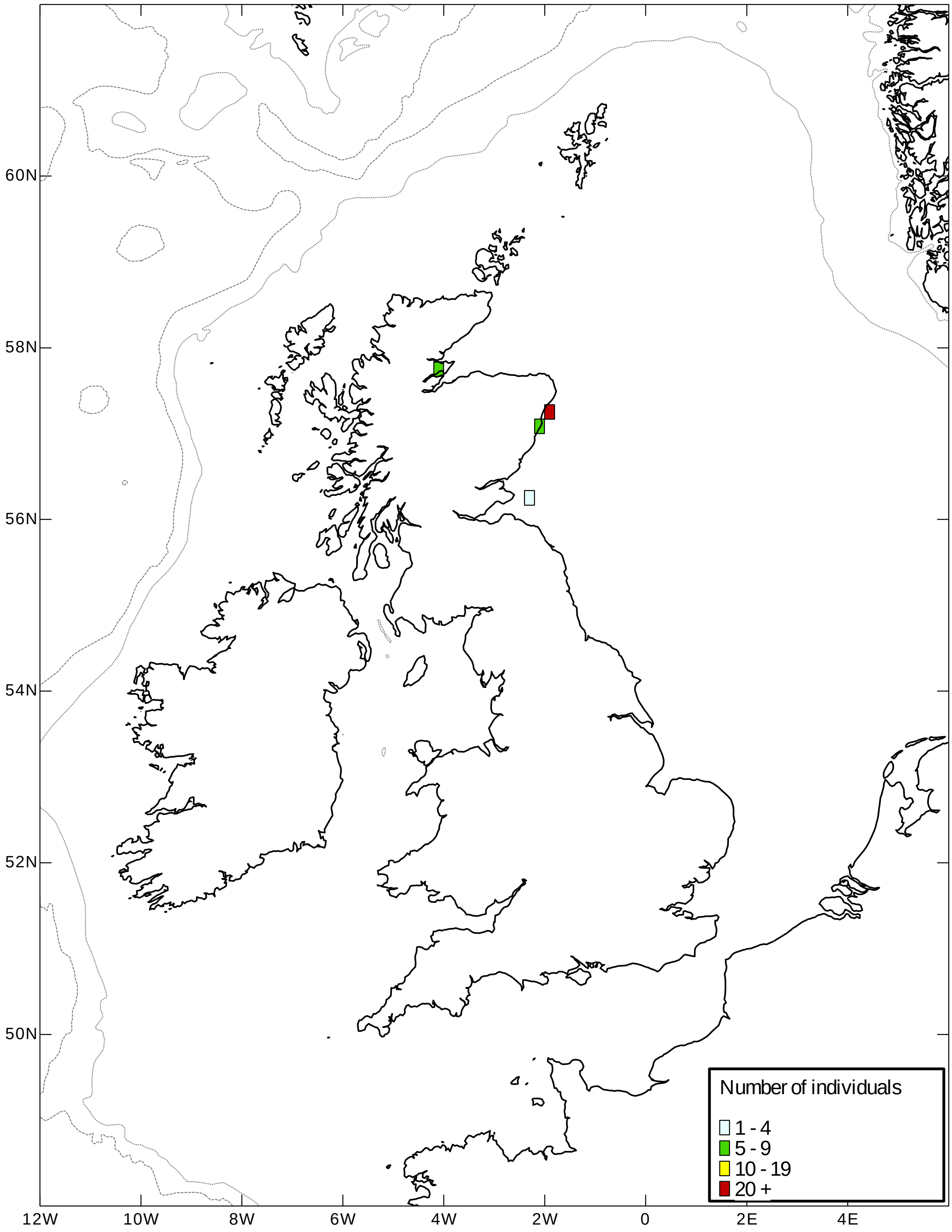

Figure 15. Bottlenose dolphins encountered during projects using explosives, 2010-2021.

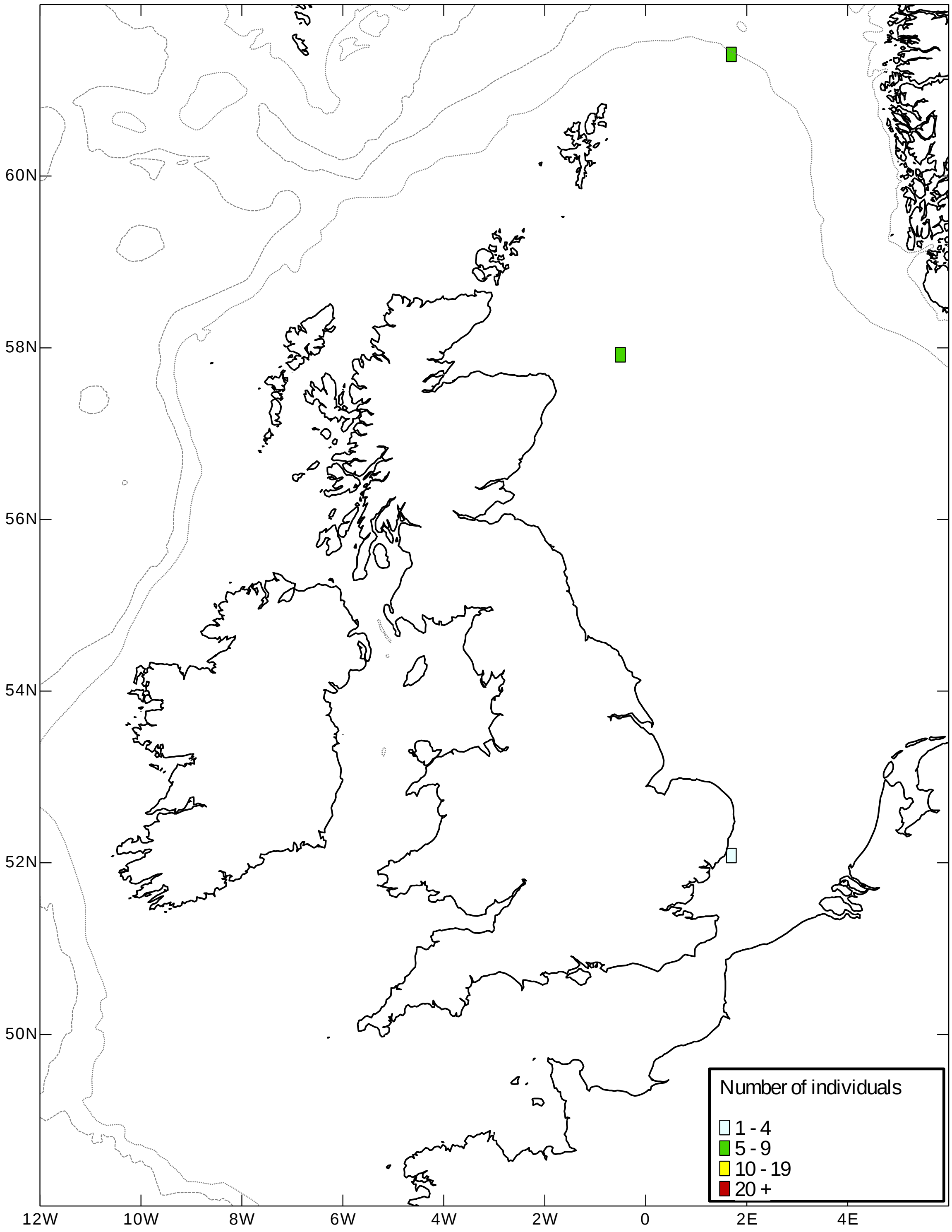

Figure 16. White-beaked dolphins encountered during projects using explosives, 2010-2021.

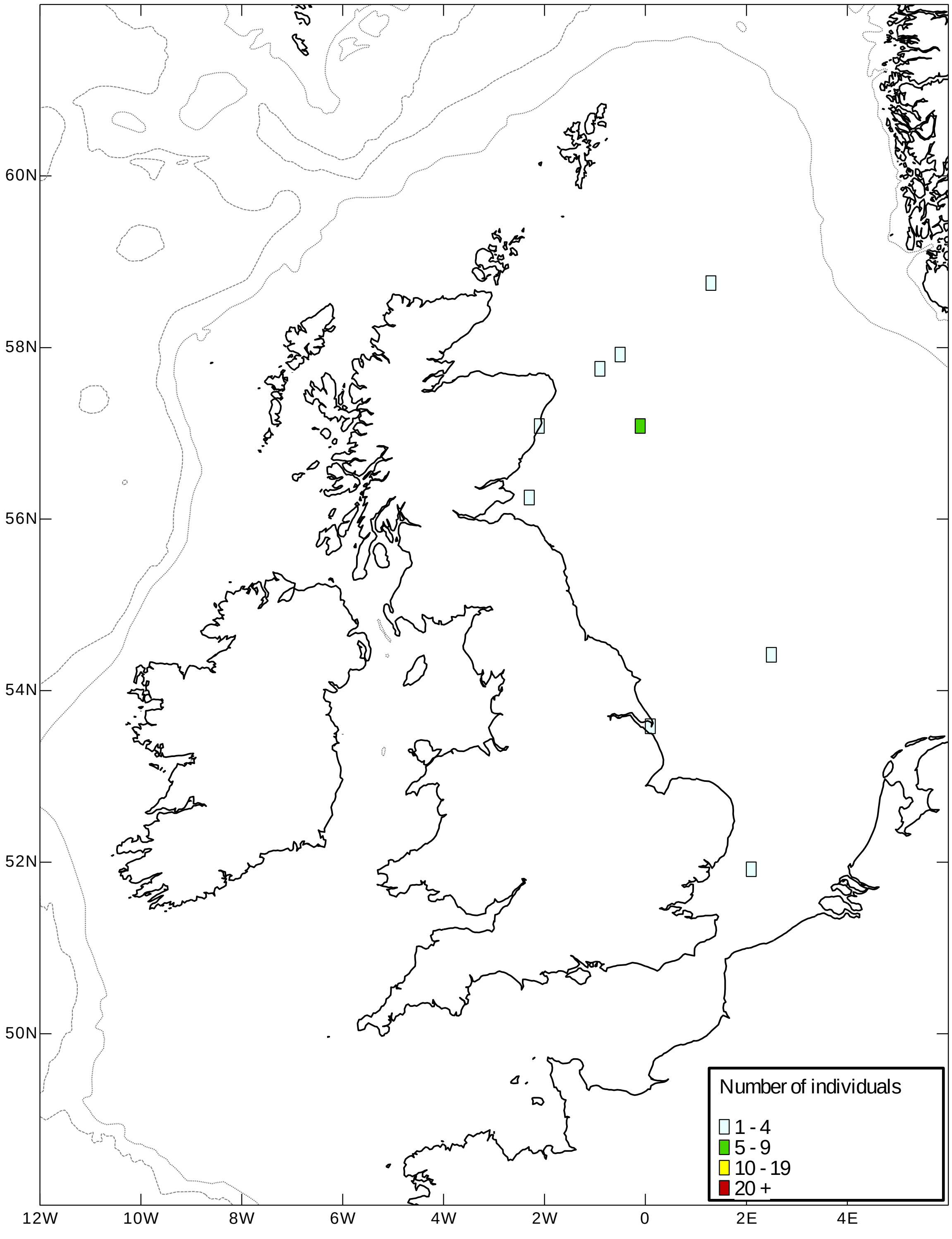

Figure 17. Harbour porpoises encountered during projects using explosives, 2010-2021.

Appendix 2 - Recommended items for Marine Mammal Recording Forms (explosives)

Cover Page:

- Regulatory reference number
- Country
- Location (e.g. OWF name)
- Quad (for O&G)
- Ship / platform name
- Client
- Contractor
- Project type (decommissioning, UXO, construction, military)
- Industry (O&G, OWF, cable / pipeline, coastal construction, military etc.)
- Start date
- End date
- Type of source (explosives, deflagration, etc.)
- Frequency (Hz)
- Intensity (dB re. 1µPa or bar metres)
- Method of soft start (none, scare charges)
- Visual monitoring equipment used
- Magnification of optical equipment
- Height of eye (metres)
- How was distance of animals estimated?
- Number of dedicated MMOs
- Training of MMOs
- Was PAM used?
- Number of PAM operators (PAM only)
- Description of PAM equipment (PAM only)
- Range of hydrophones from detonation site (PAM only)
- Depth of hydrophones (PAM only)
- ADD used (yes / no)
- ADD type
- Number of ADDs
- ADD frequency
- Comments

Operations:

- Regulatory reference number
- Ship / platform name
- Date
- Bubble curtain used?
- Time ADD on (UTC)
- Time ADD off (UTC)
- Time scare charge began (UTC)
- Time scare charge ended (UTC)
- Time of detonation (UTC)
- Fire / misfire (successful detonation, misfire, donor charge only)
- Time pre-detonation search began (UTC)
- Time search ended (UTC)
- Time PAM began (UTC)

- Time PAM ended (UTC)
- Time post-detonation search began (UTC)
- Time post-detonation search ended (UTC)
- Post-detonation search observations
- Was all monitoring (pre- and post-detonation) conducted in daylight?
- Could the full extent of the mitigation zone be clearly seen?
- Was any mitigating action required?
- Source (high-order explosives, deflagration, hydra jet, etc.)
- Type of explosive
- NEQ (kg)
- UXO NEQ (kg)
- Scare charge used
- Number of scare charges
- Minimum scare charge NEQ (kg)
- Maximum scare charge NEQ (kg)
- Seabed depth (metres)
- Downhole (yes / no)
- Downhole depth (metres)
- Comments

Effort:

- Regulatory reference number
- Ship / platform name
- Date
- Visual watch or PAM?
- Observer's / operator's name(s)
- Time of start of watch (UTC)
- Time of end of watch (UTC)
- Source activity (not active, ADD, scare charge, detonation, misfire)
- On site / in transit
- Start position - degrees latitude
- Start position - minutes latitude
- Start position - north / south
- Start position - degrees longitude
- Start position - minutes longitude
- Start position - east / west
- Depth of water at start position (metres)
- End position - degrees latitude
- End position - minutes latitude
- End position - north / south
- End position - degrees longitude
- End position - minutes longitude
- End position - east / west
- Depth of water at end position (metres)
- Speed of vessel (knots)
- Wind direction
- Wind force (Beaufort)
- Sea state
- Swell
- Visibility (visual watch only)
- Sun glare (visual watch only)

- Precipitation
- Comments

Sightings:

- Regulatory reference number
- Ship / platform name
- Sighting number
- Acoustic detection number
- Date
- Time at start of encounter (UTC)
- Time at end of encounter (UTC)
- Were animals detected visually and/or acoustically?
- How were the animals first detected?
- On site / in transit
- Observer's/ operator's name
- Position - degrees latitude
- Position - minutes latitude
- Position - north / south
- Position - degrees longitude
- Position - minutes longitude
- Position - east / west
- Water depth (metres)
- Species or species group
- Description (visual sighting only)
- Bearing to animal
- Range of animal (metres)
- Total number
- Number of adults (visual sightings only)
- Number of juveniles (visual sightings only)
- Number of calves (visual sightings only)
- Photograph taken
- Behaviour (visual sightings only)
- Direction of travel (relative to ship / platform)
- Direction of travel (compass points)
- Source activity when animals first detected (not active, ADD, scare charge, detonation, misfire)
- Source activity when animals last detected (not active, ADD, scare charge, detonation, misfire)
- Time animals entered the mitigation zone (if relevant) (UTC)
- Time animals left the mitigation zone (if relevant) (UTC)
- Closest distance of animals from detonation site (metres)
- Time of closest approach (UTC)
- First observed distance during ADD / scare charge use (if relevant) (metres)
- Closest observed distance during ADD / scare charge use (if relevant) (metres)
- Last observed distance during ADD / scare charge use (if relevant) (metres)
- What action was taken?
- Estimated loss of production (if relevant) due to mitigating actions (minutes)
- Comments

Appendix 3 - Scientific names of species mentioned in the text

Harbour seal	*Phoca vitulina*
Grey seal	*Halichoerus grypus*
Humpback whale	*Megaptera novaeangliae*
Minke whale	*Balaenoptera acutorostrata*
Long-finned pilot whale	*Globicephala melas*
Killer whale	*Orcinus orca*
Bottlenose dolphin	*Tursiops truncatus*
White-beaked dolphin	*Lagenorhynchus albirostris*
Long-beaked common dolphin	*Delphinus capensis*
Harbour porpoise	*Phocoena phocoena*
Sprat	*Sprattus sprattus*
Pollock	*Pollachius pollachius*
Saithe	*Pollachius virens*
Whiting	*Merlangius merlangus*
Poor Cod	*Trisopterus minutus*
Pout	*Trisopterus luscus*
Mackerel	*Scomber scombrus*
Garfish	*Belone belone*
John Dory	*Zeus faber*
Guillemot	*Uria aalge*

Appendix 4 - Glossary

Acoustic deterrent device (ADD): A device that emits a noise, usually medium to high frequency, with the purpose of deterring animals from a specific hazard / area. The acoustic characteristics of each device differ in terms of the sound levels produced, frequency range, temporal pattern / duty cycle, and harmonics.

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: Operating the acoustic source at its full operational level, reached at the end of a soft start.

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

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

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

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

Marine Mammal Mitigation Plan (MMMP): A document detailing the proposed marine mammal monitoring and mitigation procedures to be implemented in a project.

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

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

Mitigation zone: The area where an MMO or PAM operator keeps watch for marine mammals (and delays the start of activity should any marine mammals be detected); currently the area within 1,000 m of the detonation site.

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

Net Explosive Quantity (NEQ): The total mass of the contained explosive substances.

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

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

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

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

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

Post-detonation search: Search after a detonation for any evidence of impacts on marine life e.g. fish kills.

Pre-detonation search: Search for marine mammals prior to commencing detonations.

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

Scare charge(s): One or more small charges detonated prior to the main detonation to act as a warning and deter marine mammals from the vicinity.

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

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

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

Source: The source of the noise (e.g. an explosive charge or an ADD).

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

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