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Marine mammal observations and compliance with JNCC guidelines during pile driving operations from 2010–2021.

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Summary

Marine mammal observer (MMO) data from offshore wind farm (OWF) and oil and gas (O&G) projects involving pile driving in UK waters between 2010 and 2021 were collated. MMO reports and data were not always submitted following projects, particularly for OWF construction, where reports and data were missing for over half of the projects. Of those OWF projects that did make a submission, over half were missing either the MMO report or the data recording forms. Some of those that were missing data included some information within tables in the MMO report, but this was not always in sufficient detail to be usable. More O&G projects submitted MMO reports, compared to OWF projects, and most that did include usable data. Where data were usable, corrections were still required prior to inclusion in the database. Following quality checks, data from 41 projects between 2011 and 2021 (no data were available for 2010) were examined to assess compliance with JNCC guidelines for piling and the response of marine mammals to piling operations.

Over 4,700 hours were recorded as monitoring for marine mammals (over 3,700 hours visual monitoring and over 900 hours acoustic monitoring), with piling being undertaken for 23% of this time and acoustic deterrent devices being active for 1% of this time. The majority of monitoring was conducted on site, with only 4% of monitoring being undertaken whilst in transit.

A total of 310 sightings comprising 2,160 individual animals were encountered. There were no acoustic detections. The most frequently encountered identified species was the grey seal, followed by the harbour porpoise. Minke whales and harbour seals were also sometimes seen, plus lower numbers of other species. The distribution of encounters largely reflected survey effort and known species distribution.

Most projects did not include any measures to reduce the level of sound produced. Three projects used vibratory piling part of the time, which would have produced lower levels of sound. One project using impact piling and modified the cushion between the hammer and pile, which would also have resulted in lower levels of sound.

OWF projects used two dedicated MMOs more often than O&G projects. Where PAM was used, in most cases there was only one PAM operator. On three O&G projects, a single person was used as a dual role MMO / PAM operator. Although PAM was used less often on OWF projects, there were no cases where a single person undertook a dual role.

PAM was used more often on O&G projects than OWF projects; 79% of O&G projects used PAM compared to 38% of OWF projects. All projects where the licence (where available for examination) required acoustic monitoring used PAM.

During the period 2011–2021, compliance with the requirements for visual pre-piling searches was generally good, although varied between years. Overall, visual searches were compliant more often on O&G projects than on OWF projects. PAM was used most often on O&G projects and when it was used on these projects there was always an adequate acoustic pre-piling search at night; however, O&G projects did not usually use PAM during the day to supplement the visual search. Fewer OWF projects used PAM, but where they did there was always an adequate acoustic search at night and usually also in the day, although sometimes this was at the expense of a visual search.

Acoustic deterrent devices (ADDs) were only used before piling commenced on OWF projects, where they were used on 51% of occasions. Compliance was generally good where the licence required ADDs to be used prior to piling. Cases of non-compliance were

mostly due to ADDs not being used although some were due to ADDs being used for a different duration than required. There were several occasions when ADDs were activated when marine mammals were in the mitigation zone or had only recently left the mitigation zone.

There were 20 occasions between 2011 and 2021 when piling was required to be delayed due to the presence of marine mammals within the mitigation zone. Delays were mostly required for grey seals, with occasional delays for other species. Only two delays were on O&G projects, the remainder were on OWF projects. Delays seemed more prevalent on projects closer to the coast. For 13 of the 20 delays, there was at least 20 minutes between the last detection in the mitigation zone and piling commencing (the minimum recommended); on five occasions piling was delayed for less than 20 minutes and on two occasions there was no delay. In one case, although piling was delayed for at least 20 minutes, an ADD was used to deter a harbour seal from the mitigation zone to little effect.

Most soft starts for impact piling between 2011 and 2021 met the required minimum duration (20 minutes). Standards were higher for OWF projects than O&G projects; on 12% of occasions there was no soft start on O&G projects, compared to 3% for OWF. For both project types, there was sometimes no soft start following a break in piling, even where breaks were longer than the 10 minutes allowed in the JNCC guidelines before another soft start is required. O&G projects also had more prolonged soft starts than OWF projects. There was no soft start for vibratory piling and pile drilling, although these piling methods were not used often. There were two occasions when the soft start was stopped due to grey seals in the mitigation zone.

Where there was a break in piling of more than 10 minutes, there was usually a pre-piling search on O&G projects but compliance with this requirement was lower for OWF projects. Soft starts were rarely used following a break in piling.

Piling started at night on one third of occasions reviewed. As PAM was not used on most OWF projects, there was often no acoustic monitoring before commencing piling at night on these projects but ADDs were used instead. On O&G projects, PAM was usually used before starting at night. For both O&G and OWF projects, there were a few occasions when piling started at night with no mitigation other than a soft start. There were relatively few occasions when piling was known to have started in poor conditions for visual monitoring in daylight. When this was the case, PAM was sometimes used to supplement visual monitoring on O&G projects, while OWF projects used ADDs.

Variations from the standard JNCC mitigation protocol were sometimes agreed with the regulator. These were sometimes less stringent than the standard protocol and sometimes more stringent. Examples included changes in the size of the mitigation zone, the duration of the pre-piling search, the duration of the soft start, the duration of delays, and the use of ADDs and a soft start in place of monitoring with MMOs and PAM operators.

The low number of sightings limited the ability to examine the response of marine mammals to piling, particularly for individual species. Where data could be analysed, sample sizes were low, so the results should be treated with caution. Detection rates of grey seals and the combined groups of all seals, all cetaceans and all delphinids were significantly reduced during periods of impact piling compared to when piling was not ongoing. However, there was no evidence of a further decline in cetacean detections after impact piling commenced on a project. Seals were only occasionally seen while impact piling was being conducted but remained significantly further from the pile compared to when piling was not ongoing.

During pile drilling, there were no significant differences in detection rates of seals (grey or all species combined) in relation to piling, or the closest distance of approach to the pile. Significantly fewer seals (all species combined) were hauled out when pile drilling was occurring but there was no evidence of significant avoidance or travel away from the piling platform at these times. There were insufficient data to examine responses of marine mammals to vibratory piling.

There were nine sightings of marine mammals when ADDs were active. Some animals disappeared and/or were recorded as swimming away, but others (particularly seals) were not deterred. Some animals were already present before the ADD was activated; seals that were in the mitigation zone disappeared shortly after activation, although one grey seal initially approached the ADD and pile while the ADD was active, approaching to 1m from the pile before swimming away. Others appeared after the ADD was activated, with seals appearing close to the pile. One harbour seal appeared when the ADD had been active for some time and approached the pile and was reported as trying to climb it while the ADD was active, remaining in the mitigation zone for 51 minutes.

There were only four sightings during the soft start of impact piling; none were recorded as swimming away although all were only seen briefly during the soft start period.

The results of the present study and other studies are used to make recommendations for items to be considered when the piling guidelines are next revised. These include: a greater emphasis on noise abatement; a conservative approach when variations from the guidelines are allowed; continued monitoring alongside the use of ADDs; caution in the use of ADDs to reduce the risk of TTS and far-field disturbance; restrictions on starting at night or in poor monitoring conditions; clarifying that PAM should not be used as a substitute for visual monitoring except during hours of darkness or in restricted visibility such that the full extent of the mitigation zone cannot be seen; providing sufficient numbers of MMOs and PAM operators; recommending that mitigation personnel are on the installation vessel; clarification of the correct timings when a delay is required; consideration of how best to achieve a soft start; revision of procedures following a break in piling; 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 piling operations are also made.

Contents

1 Introduction

Anthropogenic noise in the world's oceans, and its potential impacts on marine mammals and other marine fauna, has attracted much attention in recent years. Potential impacts of noise on marine mammals include behavioural changes, masking of biologically important sounds and, if received levels are high enough, injury (Richardson *et al.* 1995). Impulsive noise, such as that produced during impact pile driving, 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). There is general consensus that piling noise during the construction phase is potentially the most harmful impact to marine mammals in offshore wind farm (OWF) projects (Madsen *et al.* 2006; ICES 2010; Simmonds & Brown 2010; Harwood & King 2014; Verfuss *et al.* 2016b). In addition to the risk of injury, there is also potential for behavioural disturbance and displacement with piling being audible to marine mammals at considerable distances (Thomsen *et al.* 2006; Bailey *et al.* 2010; Kastelein *et al.* 2013a, 2013b) and impacts extending sometimes to tens of kilometres away from the construction site (Tougaard *et al.* 2009, 2013a; Brandt *et al.* 2011, 2016; Dähne *et al.* 2013).

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 pile driving were first introduced in 2009 and were revised in 2010 (JNCC 2010); 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 operations and delay piling 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 piling. When piling is clear to commence, there should be a gradual ramping up of piling power (the soft start). 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 piling 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) and analysis of mitigation data collected during explosives works has been completed (Stone 2023c). The current study presents a similar analysis of MMO and PAM data from pile driving operations in UK waters between 2010 and 2021 to assess both compliance with JNCC guidelines and marine mammal behavioural responses to piling. The scope of the study includes data from OWF construction and piling by the oil and gas industry (O&G).

2 Methods

2.1 Marine mammal observations and effort

Marine mammal observations were undertaken during pile driving operations in UK waters on both O&G and OWF projects. This report examines all data received 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 during night-time operations and sometimes also during the day. 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 pile 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 piling 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.

As the recording forms were designed for geophysical surveys, there was no facility for recording the use of ADDs. Additional data regarding the timings of ADD operation, where available in MMO reports, 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.

Following the quality control process, data from a total of 41 projects (33 O&G and eight OWF) were included in the database and available for analysis, spanning the period from 2011 to 2021.

2.3 Piling operations

Of the 41 projects included in the database, all but one involved impact piling. Where noted, the hammers used in impact piling were hydraulic hammers. Two O&G projects used vibratory piling alongside impact piling, while one demonstration OWF project in a coastal location used vibratory piling and pile drilling.

The specifications (energy) of the hammer used for impact piling were recorded for 33 projects (28 O&G projects and five OWF projects). For O&G projects, the least powerful hammer used was 90kJ, while the most powerful was 3,500kJ, with the majority (71%) being less than 2,000kJ. OWF projects used hammers with more energy, the least powerful being 900kJ and the most powerful 4,000kJ, with 80% being greater than 2,500kJ. However, on many occasions the energy used was less than the capability of the hammer.

Pile diameters were not always recorded. Where they were recorded, for O&G projects pile diameters varied between 0.6m and 2.6m. Pile diameters of 2.1m and 2.5m were recorded for two OWF projects; diameters were not recorded for the other OWF projects but some would have had larger diameter monopiles.

The source level of piling was only recorded for five O&G projects, but where it was recorded source levels varied between 134 $dB^{pk\text{-}pk}$ re.1µPa@1m and 201 $dB^{pk\text{-}pk}$ re.1µPa@1m (where recorded, these were for 90kJ hammers).

For five of the eight OWF projects ADDs were used to deter marine mammals before piling commenced (one further OWF project for which data were missing used an ADD occasionally). In all cases, a Lofitech Seal Scarer was used (except the project where data were missing, for which the type of ADD was unspecified). Four projects used one ADD while one used two devices simultaneously. The Lofitech device emits an acoustic signal with frequencies between 10 and 20kHz and a source level of 189 dB re.1µPa@1m.

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 O&G and OWF projects (one quadrant = 1º latitude x 1º 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 piling guidelines and licence conditions (where known) was examined for all occasions when piling was conducted. Where appropriate, data for O&G projects were analysed separately from OWF projects to assess practices in each industry.

2.5.1 Noise abatement

The JNCC piling guidelines encourage the use of Best Available Technique (BAT), e.g. hammer modifications, use of vibratory hammers, etc., to reduce levels of noise. MMO reports were examined for any instances where efforts were made to reduce the level of noise produced by piling.

2.5.2 MMOs and PAM operators

The number of dedicated MMOs per project was assessed for the different industries. 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 industries. 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-piling search

Pre-piling searches were required any time piling commenced after a period of silence of more than 10 minutes. A search of adequate duration was defined as beginning 30 minutes before piling commenced and not terminating before piling commenced.

The proportion of occasions when pre-piling searches were adequate was assessed for visual searches during daylight hours and for acoustic searches during the day and at night. Night-time acoustic searches were assessed for those projects where it was known that the licence required PAM to be used at night (where licences were available for examination). In addition, as licences were often not available for examination, night-time and daytime acoustic searches were assessed for all projects where PAM was used. The proportion of adequate pre-piling searches at dawn or dusk by visual and/or acoustic means was also assessed.

2.5.5 Acoustic deterrent devices

For projects where licences (when available for examination) required that ADDs were used, the data were examined to ascertain whether they were used for the duration specified in the licence.

The JNCC piling guidelines say that ADDs should be switched on throughout the pre-piling search, but do not specify a period of monitoring beforehand. Nevertheless, the data were examined to see what monitoring practices were prior to the use of ADDs. The guidelines say that ADDs should be switched off immediately after piling commences; when ADDs were switched off in relation to piling 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, if any, were put in place.

2.5.6 Delays in operations

The data were examined for occasions when piling was required to be delayed due to the presence of marine mammals in the mitigation zone. In addition, for projects where an MMO report was received but there were no data, the report was examined for any records of delays. Where data were available, the number of occasions when a delay was required was compared to the number of occasions when piling was conducted. The JNCC guidelines say that piling should not commence if marine mammals are detected in the mitigation zone or until 20 minutes after the last visual or acoustic detection. Most Marine Mammal Mitigation Plans for projects interpreted this as a delay until 20 minutes after the last detection in the mitigation zone. Delays were therefore regarded as implemented correctly if there was at least 20 minutes between the last detection in the mitigation zone and the soft start commencing and the subsequent soft start lasted the required minimum duration (or stopped before full power was reached).

2.5.7 The soft start

The JNCC guidelines require that a soft start is performed when commencing piling (unless there has been a break in piling of no more than 10 minutes). The soft start aims to protect any undetected marine mammals in close proximity by utilising a gradual build-up of power to allow them to leave the area before full power is reached.

The duration of soft starts was examined for all occasions when piling commenced after a period of silence of more than 10 minutes and full power was reached, except for the few occasions where there was an exemption from performing a full soft start as agreed with regulators and/or JNCC and highlighted within the MMO report. The JNCC guidelines state that the gradual build-up of power should be at least 20 minutes to allow adequate time for marine mammals to leave the area. The proportion of soft starts that lasted the required minimum duration (from commencement until full power) was assessed, as was the proportion of occasions when there was no soft start. The JNCC piling guidelines do not recommend a maximum duration for the soft start, but the proportion of prolonged soft starts was also examined.

2.5.8 Breaks in operations

The JNCC guidelines require that there is a full pre-piling search and soft start before piling recommences after any breaks in piling longer than 10 minutes. All breaks of more than 10 minutes were examined to see whether there had been a search of at least 30 minutes (visual or visual + PAM in daylight, PAM at night, visual and/or PAM at dawn or dusk) and a soft start of at least 20 minutes.

2.5.9 Piling at night or in poor conditions

The JNCC guidelines say that piling should not commence at night or in poor visibility or during periods when the sea state is not conducive to visual mitigation (above sea state 4), although variations may be permitted. The number of times when piling commenced at night or in poor conditions was assessed; for poor conditions this could only be assessed where weather had been recorded on the Effort forms. Due to the sea state categories recorded on the forms it was not possible to distinguish sea states above 4, as the 'choppy' category was equivalent to both sea states 4 and 5, so 'rough' seas (equivalent to sea state 6 and above) was used. Poor conditions were therefore defined as 'rough' sea states or swell > 4m or visibility < 1km.

2.5.10 Variations from the standard protocol

MMO reports and licences (where available) were examined for any instances where variations from the standard mitigation protocol were allowed, e.g. a different size mitigation zone or different duration of soft start. Where there were agreed variations, these were accounted for when assessing the aspects of compliance noted above.

2.6 Response of marine mammals to piling

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 had no accompanying effort data so could not be used where detection rates per unit effort were calculated; for some other aspects of analysis, effort data were not necessary, and all sightings and acoustic detections were used.

Due to the different characteristics of the different methods of piling (see Section 2.3), these methods were analysed separately. The analysis methods used were the same regardless of piling method, so the following sections outlining methodology apply to all types of piling.

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), for example, the delphinids group included both white-beaked dolphins and unidentified dolphins, amongst other species.

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

Pinnipeds	Mysticetes	Delphinids
Seal sp.	Fin / sei / blue / humpback whale	Delphinid sp.
Grey seal	Fin / blue whale	Long-finned pilot whale
Harbour seal	Fin whale	Killer whale
	Minke whale	Dolphin sp.
		Risso's dolphin
		Bottlenose dolphin
		White-beaked dolphin
		Atlantic white-sided dolphin
		Common dolphin

2.6.2 Detection rates in relation to piling activity

Monitoring often commenced in the days prior to operations commencing, as preparations were made. As there were usually multiple piles to be driven in each project, piling was intermittent with periods of no piling between periods of piling. Detection rates of marine mammals were compared between periods of piling and not piling. Due to low effort during vibratory piling, sufficient data were only available to compare detection rates for impact piling and pile drilling.

Matched pairs (piling versus not piling) were used where for each pair the project, ship, month, observer, and weather conditions (wind force, sea state, swell, visibility, sun glare and precipitation) were the same. As there were no acoustic detections, only visual effort and detections were used. Temporal and spatial variations were controlled by having all observations within each matched pair being within the same month on the same project; monitoring effort and detections whilst on transit to the site were excluded. The resulting matched pairs (piling versus not piling) 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). As sample sizes were low, detection rates could only be compared for the combined species groups of all seals, all cetaceans or all delphinids and for the grey seal.

To test whether there was a general decline in occurrence of marine mammals after operations first commenced on a project, matched pairs (prior to piling first commencing versus after) were used where for each pair the project, observer and weather conditions (sea state, swell and visibility) were the same. Only visual effort and detections were used and monitoring effort and detections whilst on transit to the site were excluded. The resulting matched pairs (prior to piling first commencing versus post piling commencing) were tested using the Wilcoxon signed ranks test. As sample sizes were low, detection rates could only be compared for the combined species group of all cetaceans and only impact piling could be examined.

2.6.3 Closest distance of approach to the pile (piling versus not piling)

The closest distance of approach to the pile during an encounter was compared between periods when piling was being conducted and periods when it was not. Periods of piling included times when the energy level was at full power, when undertaking a soft start or when the energy level was reduced for some reason other than a soft start. As the closest approach could occur at any point during an encounter, only those encounters where piling was either active or inactive throughout the whole encounter were used. Due to low numbers of detections, particularly when piling, the influence of weather or observer ability was not able to be controlled for. As there were no sightings during periods of piling on projects using vibratory piling, the closest distance of approach could only be compared for impact piling and pile drilling. Pile drilling occurred on one project in a coastal location, where seals were sometimes observed hauled out on rocks. Only seals in the water were considered when comparing the closest distance of approach to the pile.

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

2.6.4 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. The frequency of occurrence of each recorded behaviour was compared between periods of piling and not piling, using only sightings where piling activity / inactivity remained the same throughout the encounter. Piling was regarded as active whether it was at full power, undertaking a soft start or at reduced power for some reason other than a soft start.

The chi-squared test was used to compare the observed frequency with the expected frequency had there been no difference between groups (piling versus not piling). The chi-squared test for two groups requires that expected frequencies in both groups are at least five (Siegel & Castellan 1988). This condition could not be met during impact piling or vibratory piling due to the low number of sightings while piling, therefore behaviours could only be analysed for pile drilling. Due to low numbers of detections of individual species, combined species groups were used to increase the sample size.

Any marine mammal sightings occurring during ADD activation or during the soft start were examined, paying attention to the animals' behaviour at these times.

3 Results

3.1 Data submission and quality

Between 2010 and 2021, 51 O&G projects were identified as involving piling, of which MMO reports and/or data were received from 36 (71%). No reports or data were received for the remaining 15 projects, but records show that 11 of these may not have had mitigation included in the licence. Of the 36 projects where reports and/or data were received, all had a report, but one was missing data and for two projects the data were discarded due to poor quality. Data for 33 O&G projects were of acceptable quality to be included in the database after checks and corrections (65%).

Only 11 of 25 licensed OWF construction projects involving piling between 2010 and 2021 submitted MMO reports and/or data (44%). Of these 11 projects, two lacked a report (but sent data), while for five the data recording forms were missing. For the five projects where recording forms were missing, some information was included in tables within the report. For three of these there was insufficient detail to retrieve usable data, while for the other two there was sufficient detail to populate the recording forms although in both cases there was no information for most of the project (information was recorded for only 9 of 87 monopiles and 27 of 174 monopiles respectively). For six projects, data were submitted in the Excel recording forms (although for one project there was only a pdf copy). In total, usable data, whether in the recording forms or embedded in the report, were received for only eight (in whole or in part) of the 25 licensed OWF projects (32%), and for one of these Effort and Operations data were missing and only Sightings data were available.

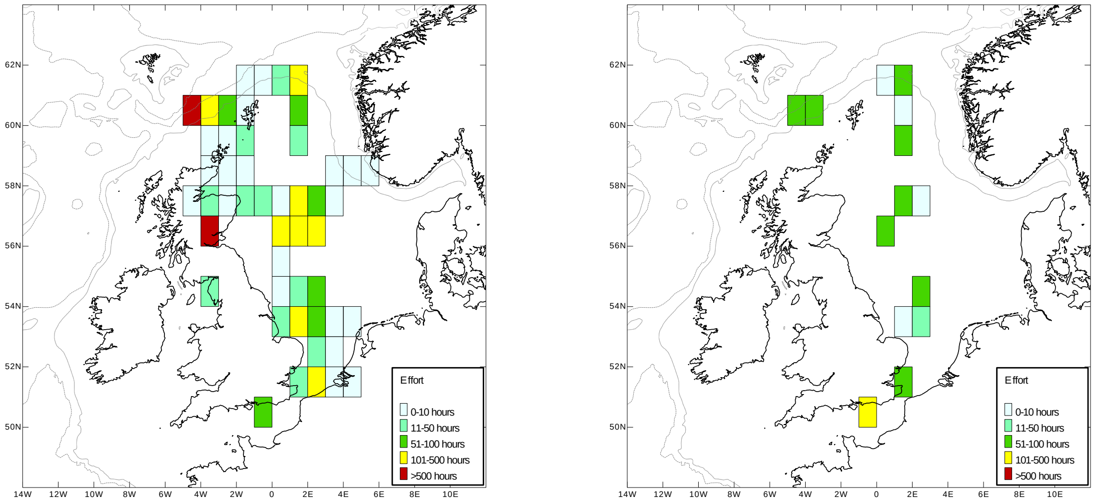
The 41 projects with usable data (33 O&G and eight OWF) spanned the period from 2011 to 2021. No usable data were received for 2010. Where data were usable, corrections were still required prior to inclusion in the database. Typical errors included times of source activity not corresponding between the different forms, inconsistencies in the way of recording soft starts or breaks in piling, wrong dates, 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 in MMO reports. Whilst most projects (83%) included in the database noted details of the size (potential maximum energy) of hammer used, fewer noted the maximum energy actually used when driving each pile or the diameter of piles (48% and 54% of projects noted these parameters respectively). For four of the five projects with data where ADDs were used, the timing or duration of ADD use was detailed in the MMO report and could be added prior to inclusion in the database, but for one project this information (together with other operational data) was missing.

3.2 Overview of survey effort and species distribution

Observations encompassed 49 quadrants (1^{o} 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 4,713 hours 17 minutes were recorded as monitoring for marine mammals between 2011 and 2021; of this, 3,725 hours 38 minutes were recorded for visual monitoring and 987 hours 39 minutes for acoustic monitoring. Piling was active for 23% of the total time spent monitoring and ADDs were active for 1% of the time.

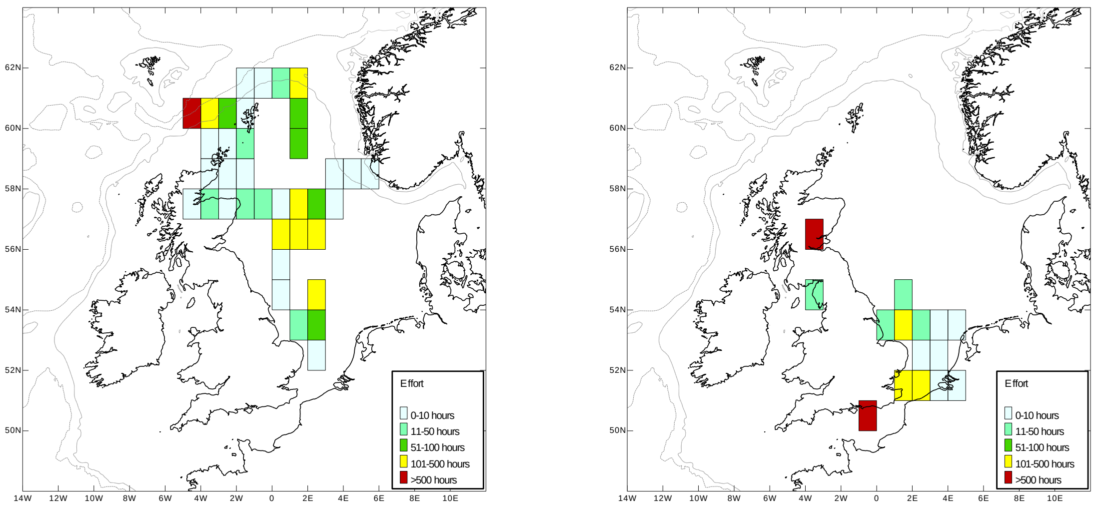
Overall, there was much less acoustic monitoring than visual monitoring, although occasionally the number of hours of acoustic monitoring in a quadrant exceeded the number of hours of visual monitoring (Figure 1). Whilst some monitoring was undertaken during vessel transit, which sometimes was from foreign ports, this was always visual monitoring with PAM being limited to periods spent on site. Only 4% of total monitoring effort (6% of visual effort) was whilst on transit.



a) Visual monitoring b) Acoustic monitoring

Figure 1. Visual and acoustic monitoring effort during piling projects, 2011-2021 (scale: 1° quadrants).

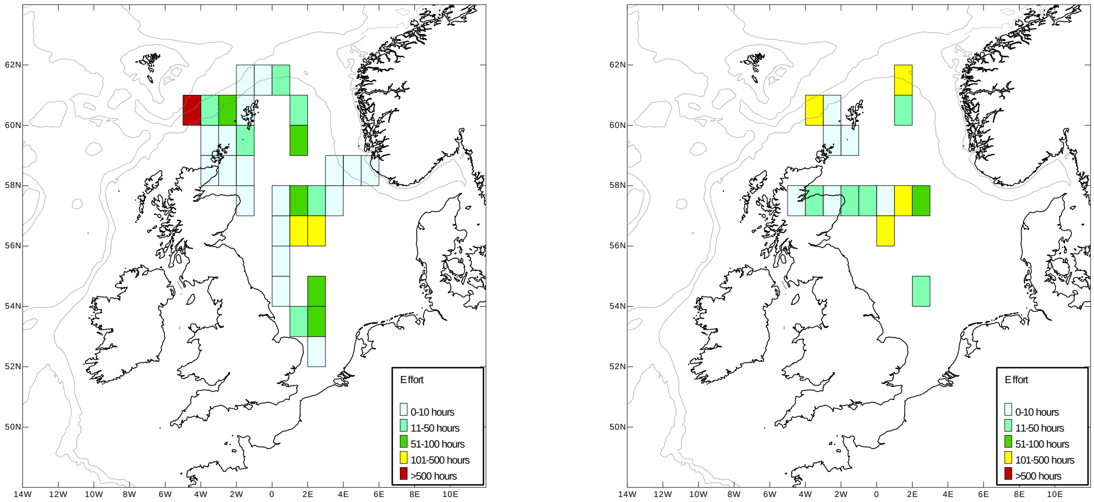
More O&G projects provided data than OWF projects and there was correspondingly more monitoring effort for O&G projects than OWF projects; O&G projects also encompassed a wider area (Figure 2). A total of 2,871 hours 11 minutes were spent monitoring for O&G projects, whereas 1,343 hours 48 minutes were spent monitoring for OWF projects. Although fewer OWF projects used PAM, acoustic monitoring was used relatively more often on these projects (27% of monitoring was acoustic) than on O&G projects (17% of monitoring was acoustic).



a) O&G projects b) OWF projects

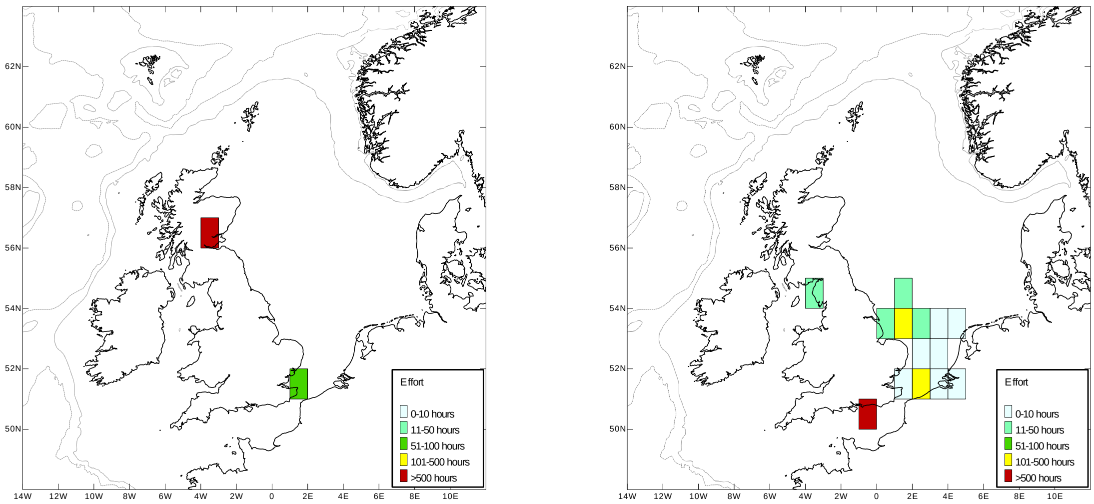
Figure 2. Monitoring effort (visual and PAM combined) during O&G and OWF piling projects, 2011-2021.

There were temporal variations in monitoring effort between years (Figure 3 and Figure 4). There was more monitoring during piling for O&G projects between 2011 and 2015 than in later years, but the opposite was true for OWF projects. There were data for only two OWF projects prior to 2016, one being a coastal demonstration project. For most earlier OWF projects (pre-2016), either no MMO report or data were received, or only summary data with insufficient detail were submitted. For O&G projects, there was a seasonal variation in monitoring effort, with more during the spring and summer months than at other times of year (Figure 5). For OWF projects, seasonal variation was less apparent (Figure 6).



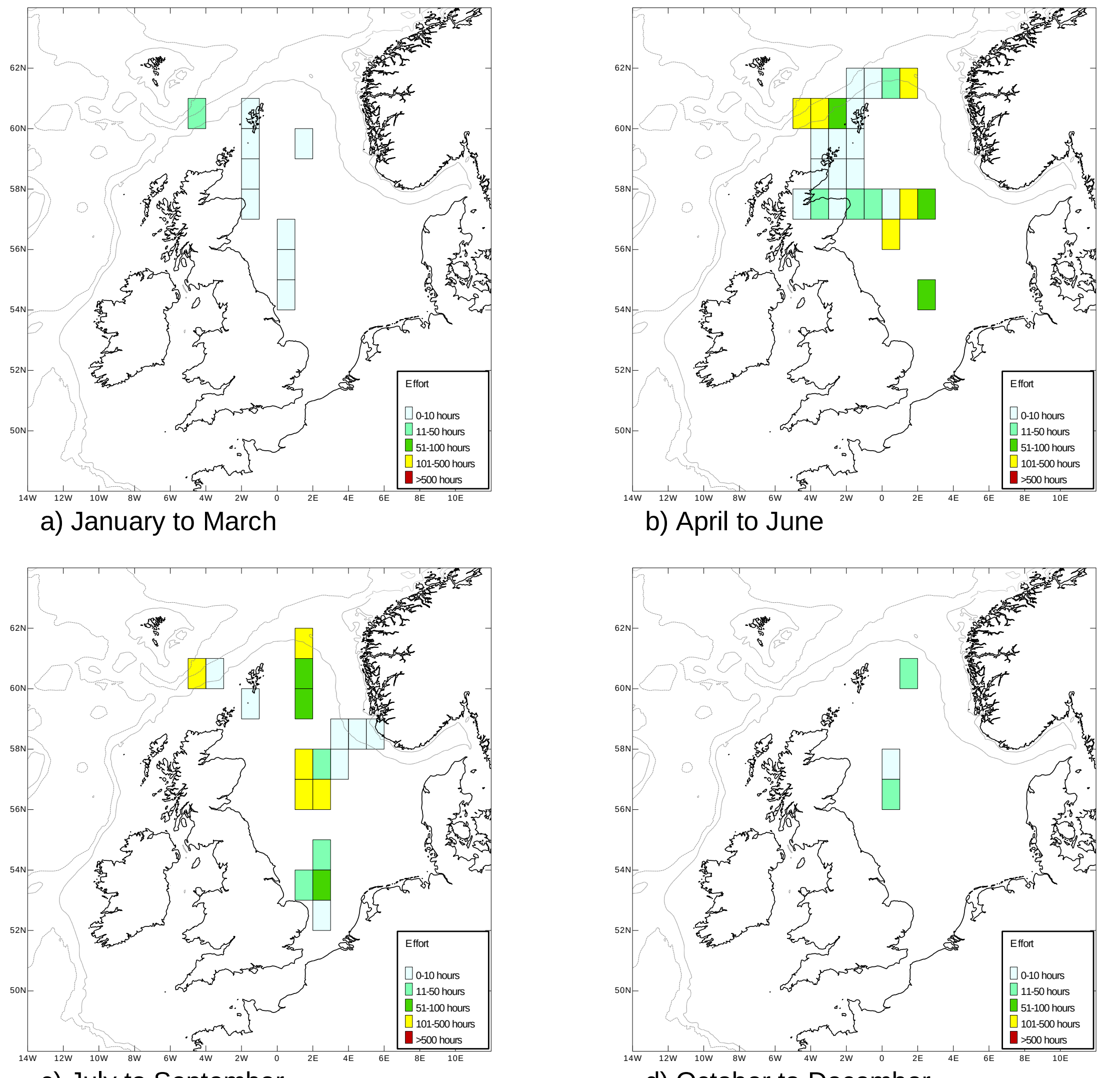
a) 2011–2015 b) 2016–2021

Figure 3. Temporal variation in monitoring effort (visual and PAM combined) during O&G projects throughout the period from 2011–2021.



c) 2011–2015 d) 2016–2021

Figure 4. Temporal variation in monitoring effort (visual and PAM combined) during OWF projects throughout the period from 2011–2021.



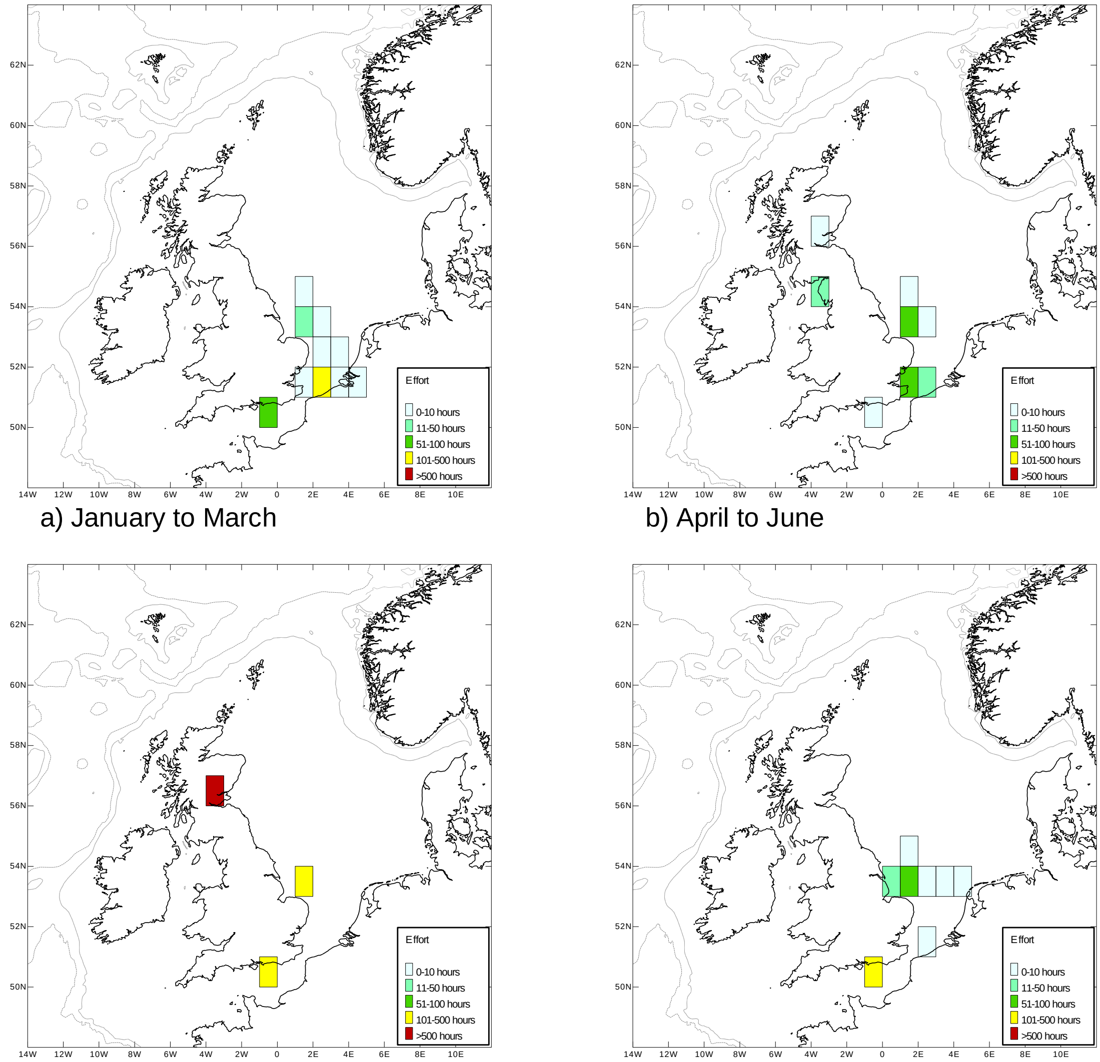
a) January to March

b) April to June

c) July to September

d) October to December

Figure 5. Seasonal monitoring effort (visual and PAM combined) during O&G projects from 2011–2021 (all years combined).



a) January to March
b) April to June
c) July to September
d) October to December

Figure 6. Seasonal monitoring effort (visual and PAM combined) during OWF projects from 2011–2021 (all years combined).

A total of 310 marine mammal sightings comprising 2,160 individual animals were encountered; 82 of these sightings were whilst on transit to or from sites. There were no acoustic detections. The most frequently encountered identified species was the grey seal (Table 2), followed by the harbour porpoise (an encounter being one or more animals occurring together). Minke whales and harbour seals were also seen, with lower numbers of other species. There were two mixed species sightings, both involving long-finned pilot whales, once with Risso’s dolphins and once with unidentified dolphins. In addition to marine mammals, there was one sighting of an individual basking shark.

Table 2. Marine mammal encounters during piling projects in UK waters from 2011–2021 and estimated number of individuals. Encounters with mixed species groups are listed under each species but are only counted once in the total of sightings.

Species	No. sightings	No. individuals
Seal sp.	67	250
Grey seal	76	78
Harbour seal	20	37
Cetacean sp.	18	24
Whale sp.	4	4
Fin whale	2	2
Fin / sei / blue / humpback whale	1	1
Fin / blue whale	1	1
Minke whale	22	22
Long-finned pilot whale	10	184
Killer whale	10	111
Delphinid (dolphin / long-finned pilot / killer / false killer whale)	1	1
Dolphin sp.	16	88
Risso's dolphin	2	4
Bottlenose dolphin	9	48
White-beaked dolphin	6	29
Atlantic white-sided dolphin	3	1,180
Common dolphin	1	2
Harbour porpoise	43	94
Total	**310**	**2,160**

There were clusters of sightings at projects in the southern North Sea and off the far north-east coast of Scotland (Figure 7). Many of the sightings in the Moray Firth were seen whilst in transit, as were some sightings running down through the northern and central North Sea and across the southern North Sea from the Netherlands. There were a small number of sightings on projects to the west and north-east of Shetland and also in the English Channel.

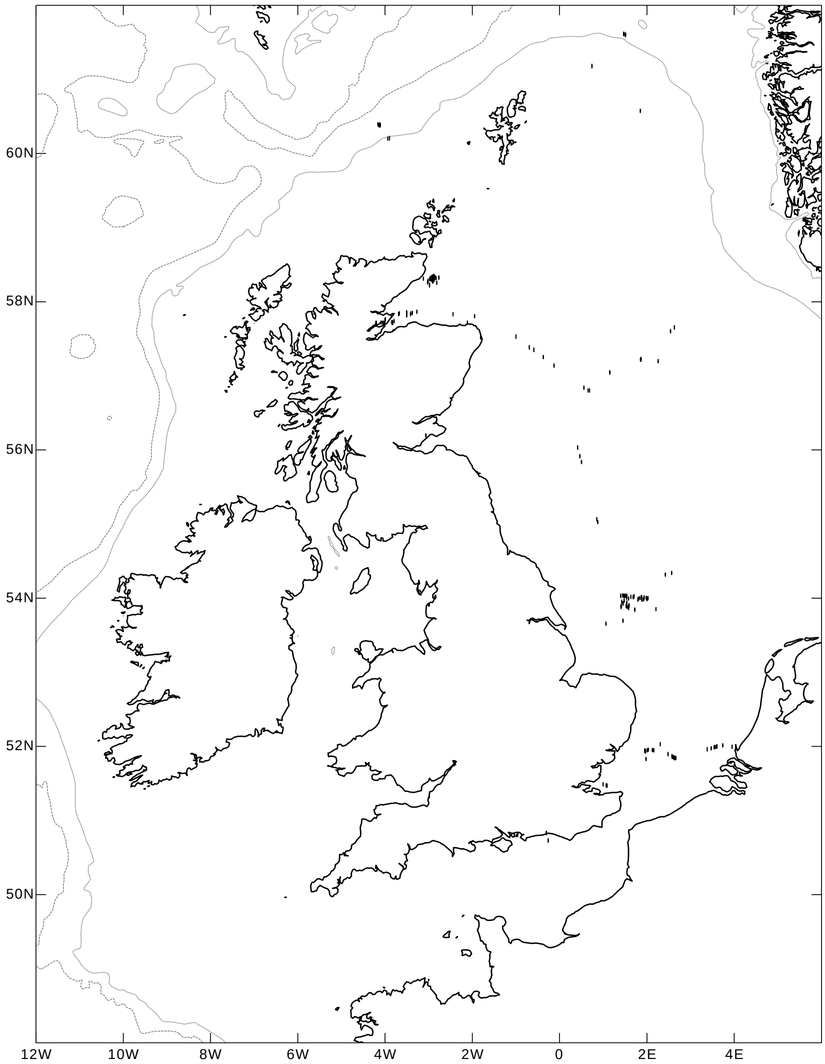


Figure 7. Sightings of marine mammals during piling projects, 2011-2021.

Individual species maps are included in Appendix 1 (Figure 14 to Figure 26). Grey seals were seen in both the southern and northern North Sea, with highest numbers seen in the Firth of Forth and the Moray Firth (Figure 14). Harbour seals were also seen in the Moray Firth and in the southern North Sea, with highest numbers close to the Netherlands coast (Figure 15). Fin whales, long-finned pilot whales, killer whales, Risso's dolphins and Atlantic white-sided dolphins were seen in more northern waters including deeper waters to the west of Shetland (Figure 16, Figure 18, Figure 19, Figure 20 and Figure 23). Minke whales and white-beaked dolphins had a more widespread distribution, occurring throughout the North Sea as well as to the west of Shetland (Figure 17 and Figure 22). The Moray Firth had concentrations of minke whales, bottlenose dolphins and harbour porpoises (Figure 17, Figure 21 and Figure 25) as well as seals. Bottlenose dolphins were also seen in the Firth of Forth. Harbour porpoises were also seen in the southern North Sea and were the only species to be seen on the English Channel coast. The only sighting of a common dolphin was in the southern North Sea (Figure 24) while a single basking shark was seen off the north-east coast of Scotland (Figure 26).

3.3 Compliance with guidelines

3.3.1 Noise abatement

There were two O&G projects that used vibratory piling for some of the time and one demonstration OWF project that also used vibratory piling (together with pile drilling). One O&G project using impact piling replaced the steel cushion between the hammer and the pile with a plastic one, reducing stress on the structure and the level of noise, although the MMO report did not quantify the reduction. None of the projects for which mitigation reports were reviewed used a bubble curtain during piling.

3.3.2 MMOs and PAM operators

OWF projects used two dedicated MMOs (taking shifts) more often than O&G projects; 50% of OWF projects had two MMOs (including one that had three MMOs on board for part of the time) compared to 12% of O&G projects. The remainder of the projects used just one dedicated MMO, although often there was also at least one PAM operator, and one OWF project had a dedicated ADD operator in addition to the MMO. One MMO report from an O&G project with one MMO and one PAM operator noted that there was a lack of breaks for the MMO on one day due to unpredictability of the piling schedule caused by weather and equipment malfunctions.

Where PAM was used, in most cases there was only one PAM operator. Only two of the 26 O&G projects using PAM had two PAM operators; the remainder had one PAM operator but on three of these projects a single person was used as a dual role MMO / PAM operator (there was one further project where no data were submitted where a single dual role MMO / PAM operator was also used). One of the three OWF projects using PAM had two PAM operators while the others had one PAM operator; although fewer OWF projects used PAM, there were no cases where a single person undertook a dual role.

Overall, numbers in the mitigation team were slightly higher for OWF projects than O&G projects (mean 2.1 personnel on OWF projects, 1.9 personnel on O&G projects). On OWF projects, numbers in the team were similar regardless of whether PAM was used (mean 2.0 personnel where PAM was not used, 2.3 personnel where PAM was used). On O&G projects, although PAM was used more often, when it was not used there was more often a single MMO (mean 1.3 personnel when PAM was not used, 2.0 personnel when PAM was used). Most OWF projects either had two MMOs or one MMO and one PAM operator, whereas most O&G projects had either a single MMO or one MMO and one PAM operator. However, there were two O&G projects that had a team of four (two MMOs and two PAM operators), in one case due to an extended mitigation zone for harbour porpoises.

3.3.3 Use of PAM

PAM was used more often on O&G projects than OWF projects; 79% of O&G projects used PAM compared to 38% of OWF projects. All projects where the licence (where available for examination) required acoustic monitoring used PAM. There were no acoustic detections reported for any project examined.

Some reports noted difficulties when using PAM caused by background noise (e.g. vessel thrusters, engine noise, propeller noise, cavitation and general noise due to equipment and vessels nearby).

3.3.4 The pre-piling search

During the period 2011–2021, compliance with the requirements for visual pre-piling searches was generally good, although varied between years (Table 3). Where searches were not compliant, it was usually because there was no search (77% of non-compliant searches). On other occasions there was a search, but it fell short of the required standard with 15% of non-compliant searches commencing too late and 9% ending prematurely. Overall, searches were compliant more often on O&G projects compared to OWF projects. A low level of compliance on OWF projects in 2016 was due mainly to one project where the Marine Mammal Mitigation Plan said that PAM should be used when sea conditions exceeded sea state 4, but the mitigation team decided to use PAM instead of a visual search whenever sea conditions exceeded sea state 2, resulting in a visual search being absent for over half of daylight operations on that project.

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

Year	O&G	OWF
2011	100 (26)	-
2012	100 (19)	-
2013	100 (2)	94.8 (58)
2014	96.3 (27)	-
2015	86.0 (50)	100 (11)
2016	90.2 (51)	47.2 (89)
2017	90.6 (32)	93.5 (46)
2018	92.3 (13)	100 (5)
2019	100 (5)	100 (6)
2020	89.2 (93)	100 (20)
2021	-	97.6 (85)
Total	91.5 (318)	82.8 (320)

Where licences were available for examination, PAM was required prior to piling at night as a licence condition for some O&G projects, and in those cases the acoustic search was always compliant (Table 4). PAM was used on other O&G projects that may have required it as a licence condition, but the licences were not available for inspection. There were also five O&G projects where PAM was used even though it was not mentioned in the licence.

PAM was used less often on OWF projects than O&G projects, but all OWF projects where it was used at night were compliant with the standard acoustic pre-piling search (Table 5). O&G projects using PAM usually did not use PAM during the day, while the few OWF projects that used PAM usually had a compliant acoustic search in the day as well as at night (Table 6).

Table 4. Percentage (and sample size) of adequate duration acoustic pre-piling searches at night on piling projects where PAM was required to be used at night as a condition of the licence (where the licence was available for examination).

Year	O&G	OWF
2011	-	-
2012	100 (4)	-
2013	-	-
2014	-	-
2015	100 (2)	-
2016	100 (2)	-
2017	-	-
2018	-	-
2019	-	-
2020	100 (2)	-
2021	-	-
Total	100 (10)	-

Table 5. Percentage (and sample size) of adequate duration acoustic pre-piling searches at night on all piling projects where PAM was used, regardless of licence requirement.

Year	O&G	OWF
2011	-	-
2012	100 (4)	-
2013	-	-
2014	100 (22)	-
2015	100 (29)	100 (6)
2016	100 (32)	100 (68)
2017	100 (8)	-
2018	100 5)	-
2019	-	-
2020	100 (31)	-
2021	-	-
Total	100 (131)	100 (74)

Table 6. Percentage (and sample size) of adequate duration acoustic pre-piling searches in daylight on piling projects where PAM was used.

Year	O&G	OWF
2011	0.0(7)	-
2012	-	-
2013	-	-
2014	0.0 (27)	-
2015	40.0 (50)	100 (11)
2016	03.9 (51)	94.3 (87)
2017	21.9 (32)	-
2018	92.3 (13)	-
2019	0.0(5)	-
2020	9.7 (93)	-
2021	-	-
Total	18.0 (278)	94.9 (98)

Pre-piling searches at dawn and dusk were done by visual or acoustic (where available) means, or by a combination of both methods. At dawn (Table 7), there was only one non-compliant search (on an OWF project). At dusk, searches on O&G projects were always compliant but those on OWF projects were often inadequate (Table 8). At dawn, most (63%) searches were acoustic, while some were visual or used both monitoring methods (28% and

10% respectively). At dusk, more searches were visual (62% visual, 21% acoustic and 18% by both means) and most non-compliant searches terminated early (presumably due to darkness where PAM was not used).

Table 7. Percentage (and sample size) of adequate pre-piling searches by visual and/or acoustic means at dawn.

Year	O&G	OWF
2011	100 (1)	-
2012	100 (4)	-
2013	100 (1)	-
2014	100 (2)	-
2015	100 (3)	100 (1)
2016	100 (5)	100 (17)
2017	100 (1)	100 (1)
2018	-	-
2019	-	-
2020	100 (2)	50 (2)
2021	-	100 (1)
Total	100 (19)	95.5 (22)

Table 8. Percentage (and sample size) of adequate pre-piling searches by visual and/or acoustic means at dusk.

Year	O&G	OWF
2011	-	-
2012	100(2)	-
2013	-	40(5)
2014	100(1)	-
2015	100 (12)	-
2016	100(2)	100 (3)
2017	100(1)	0.0 (2)
2018	-	-
2019	-	0.0 (1)
2020	100(4)	100 (1)
2021	-	42.9 (7)
Total	100 (22)	47.4 (19)

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

- Visual searches curtailed due to poor weather conditions.
- PAM being considered to be more effective than visual monitoring in the conditions and therefore used instead of visual monitoring in daylight (although no evidence was presented that PAM was more effective).
- Failure of electricity supply (for PAM).

For most projects, MMOs were based on the installation vessel. One report noted that all round monitoring was difficult due to the size of the vessel and obstructed views. In some cases where two dedicated MMOs were on board, both observed during the pre-piling search, but this only happened routinely on two O&G and one OWF project. There were four OWF projects (including two where data were missing) where MMOs and PAM operators were based on other vessels separate to the installation vessel. On one of these projects, there were two occasions where the monitoring vessel did not arrive on site in time for the MMOs and PAM operators to conduct a pre-piling search, once due to problems with the vessel and once due to lock restrictions. Piling went ahead as planned with a visual search being conducted by a designated person on the installation vessel who had received mitigation awareness training but not a JNCC-recognised MMO training course. For all projects from 2017 onwards, MMOs were based on the installation vessel.

3.3.5 Acoustic deterrent devices

All projects where the licence (where available for examination) required the use of ADDs prior to piling were OWF projects; ADDs were not used on O&G projects. They were used prior to piling on 51% of occasions on OWF projects. MMO reports noted the durations specified for ADD use in Marine Mammal Mitigation Plans that had been agreed with regulators; various deployment durations between 15 and 30 minutes were specified. On one project, a phased mitigation plan was agreed with the regulator where for most of the time ADDs were used as a substitute for monitoring (see Section 3.3.10). However, as Operations data were missing for this project, it is not included in the following results for compliance.

Although compliance was generally good, there were some occasions when ADD use was non-compliant (Table 9); 58% of non-compliances were due to ADDs not being used, 39% were due to ADDs not being deployed for long enough and 3% were due to ADDs being deployed for too long. Where ADDs were used, the minimum duration over all projects was 8 minutes, the mean duration 22 minutes, and the maximum duration 35 minutes.

Table 9. Percentage (and sample size) of occasions where ADDs were used for the specified duration prior to piling on projects where this was a licence requirement.

Year	O&G	OWF
2011	-	-
2012	-	-
2013	-	-
2014	-	-
2015	-	-
2016	-	100 (4)
2017	-	88.5 (87)
2018	-	100 (11)
2019	-	100 (17)
2020	-	75.6 (45)
2021	-	92.0 (150)
Total	-	89.5 (314)

Where ADDs were used, on 45% of occasions there was no monitoring either before or during their use (excluding the project where ADDs were used as a substitute for monitoring). The majority of these occasions occurred at night; PAM was never used with ADDs. On 20% of occasions, there was a search that began less than 30 minutes before ADD activation, while on 35% of occasions monitoring was undertaken for at least 30 minutes beforehand. Only one of the projects stated that activation of the ADD was to be delayed if a marine mammal was detected in the mitigation zone; this was for the first part of the project only and no marine mammals were seen.

On the majority of occasions (85%), the ADDs were switched off as piling began. On 11% of occasions, the ADDs were switched off before piling began (up to eight minutes before) while on the remaining 4% of occasions the ADDs were switched off after piling began (maximum five minutes after). There were some occasions when ADDs had to be redeployed as piling was not ready to commence, although it is not possible to quantify how often this happened.

There was one project where a harbour seal appeared in the mitigation zone while an ADD was active, one minute prior to the soft start commencing. The ADD was deactivated and the soft start delayed. However, the mitigation team agreed with the developer that the ADD should be reactivated while the seal was still in the mitigation zone, being activated for periods of 23-28 minutes (the normal duration for ADD use on that project) with breaks of 10 minutes in between. There was no record of this being discussed with the regulator or JNCC. The MMO report said that the 10-minute breaks were “based on prior experience to avoid habituation”, although there was no evidence provided for this. The seal remained in the mitigation zone for 51 minutes and was recorded as approaching the monopile and trying to climb it before eventually adopting a bottling posture and drifting away (see Section 3.4.3). The ADD was reactivated twice, once while the seal was in the mitigation zone and once three minutes after it had left the zone. After the second period of reactivation, the soft start commenced, the seal by then having left the mitigation zone 27 minutes beforehand. On a later occasion on the same project, another unidentified seal appeared in the mitigation zone while the ADD was active; on that occasion the seal was only seen for a short time and the ADD remained active until the soft start began 16 minutes after the seal left the mitigation zone with no delay necessary (the Marine Mammal Mitigation Plan for the project stated that there would be a delay in piling of 15 minutes if a marine mammal was detected in the mitigation zone).

There were two occasions on another project when ADDs were initially activated while seals were known to be in the mitigation zone (once a grey seal and once an unidentified seal), the seals having entered the zone while the ADD was not active. On both occasions, the seal disappeared at or shortly after the time the ADD was activated and piling did not have to be delayed. On this project, the Marine Mammal Mitigation Plan said that if marine mammals were detected in the mitigation zone ADD activation would continue.

There were also several occasions when ADDs were activated shortly after the last sighting of a marine mammal in the mitigation zone. On one project a seal was seen in the deck lights at night, being observed swimming 10 metres from the ADD, which was not active at the time. The ADD was activated five minutes earlier than planned (four minutes after the seal was last seen) “to encourage the seal to move away”. On another project there were three occasions when an ADD was activated shortly after grey seals left the mitigation zone (at three, seven and 13 minutes after) and another occasion when an ADD was activated 17 minutes after harbour porpoises were in the mitigation zone.

3.3.6 Delays in operations

Between 2010 and 2021, there were 20 occasions (including 13 occasions noted in MMO reports where data were missing) when piling was required to be delayed due to the presence of marine mammals within the mitigation zone. In comparison to the number of times when piling was undertaken, the number of delays required was low, with one delay required for every 155 piles over the whole period (= 0.6% occasions when piling was conducted).

Delays were mostly required for grey seals, with just occasional delays for other species (Table 10). Only two delays were on O&G projects (for the minke whale and the mixed species sighting of long-finned pilot whales and Risso’s dolphins), the remainder were on OWF projects. Delays seemed more prevalent on some OWF projects than others, with the 18 delays for OWF projects occurring on five projects (with one, one, three, four and nine delays per project). The projects with more delays tended to be closer to the coast. Some delays followed multiple sightings of grey seals, but it was not clear whether these were different individuals or re-sightings of the same animal. One delay occurred on the first pile of the project (following five successive sightings of grey seals and a sighting of white-beaked dolphins) but all other delays occurred after the start of the project i.e. there had been previous piling.

Table 10. Marine mammal species that piling was delayed for between 2010 and 2021.

Species	Number of delays required
Grey seal*	15
Harbour seal	1
Unidentified seal	1
Minke whale	1
Long-finned pilot whale + Risso's dolphin	1
Bottlenose dolphin	1
White-beaked dolphin*	1

* Some delays followed multiple sightings of grey seals and one delay occurred following multiple sightings of grey seals and a sighting of white-beaked dolphins.

Where data were available, there was information on both the timing of the delay and the timing of the subsequent soft start. For projects where data were missing but a report was available, there was some information about the timing of delays but little information about the subsequent soft start. For 13 of the 20 delays, there was at least 20 minutes between the last detection in the mitigation zone and piling commencing. Where information on the soft start following a delay was available, it was either more than 20 minutes in duration, or full power was not reached (once because it was stopped when a grey seal came into the mitigation zone), or there was no soft start due to vibratory piling or pile drilling (Table 11). On five occasions, piling was delayed for less than 20 minutes; three of these occasions occurred during a project where the Marine Mammal Mitigation Plan said that piling would be delayed until the animal had been tracked to outside the mitigation zone or 20 minutes had elapsed since the last detection. On two occasions there was no attempt to delay, both on OWF projects where no data were submitted. One of these occasions occurred during a break in piling; as the MMOs thought piling had finished they did not inform the crew about a sighting of a seal and piling resumed just one minute after the seal was seen. On the other occasion, the MMO report recorded a sighting of a grey seal with an accompanying note saying "Piling should have been delayed five minutes" (perhaps implying that 15 minutes had elapsed between the last detection in the mitigation zone and piling commencing) but there were no further details or explanation as to why there was no delay.

Table 11. Procedures followed when a delay in piling was required due to marine mammals in the mitigation zone.

Species	Industry	Attempt to delay	Time from last sighting in mitigation zone until piling (minutes)	Soft start duration (minutes)
Grey seal	OWF	y	20	0 (vibratory piling)
Grey seal	OWF	y	19	0 (vibratory piling)
Grey seal	OWF	y	21	0 (pile drilling)
Grey seal	OWF	n	15?	?
Grey seal	OWF	y	42	?
Grey seal	OWF	y	63	?
Grey seal	OWF	y	31	?
Grey seal	OWF	y	31	2 (soft start stopped)
Grey seal	OWF	y	6	?
Grey seal	OWF	y	0	?
Grey seal	OWF	y	24	?
Grey seal	OWF	y	21	?
Grey seal	OWF	y	21	?
Grey seal	OWF	y	22	?
Grey seal + white-beaked dolphin	OWF	y	2	?
Harbour seal*	OWF	y	27	45
Seal sp.	OWF	n	1	?
Minke whale	O&G	y	20	11 (full power not reached)
Long finned-pilot whale + Risso's dolphin	O&G	y	20	24
Bottlenose dolphin	OWF	y	19	0 (vibratory piling)

* ADD was used to deter the seal

In one case, although piling was delayed for at least 20 minutes, an ADD was used to deter a harbour seal from the mitigation zone. Repeated uses of the ADD appeared to have little effect, with the seal eventually drifting out of the mitigation zone (see Section 3.3.5).

3.3.7 The soft start

Soft starts for impact piling were performed by increasing the energy used to strike the pile with the hammer, sometimes combined with increasing the blow rate. Utilising an increase in blow rate as well as an increase in energy was employed more often for OWF projects than O&G projects (Figure 8). A soft start of increasing energy was not possible for vibratory piling, although one project using vibratory piling did increase the revolutions per minute (but did not record any details of the duration of this process). There was also no soft start for pile drilling. Vibratory piling and pile drilling were not used often, but when pile drilling was used it tended to run continuously for many hours or days at a time, resulting in fewer starts.

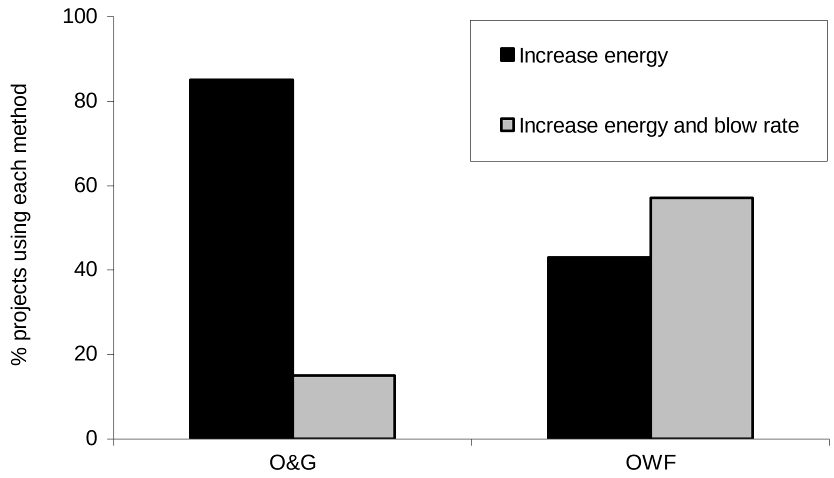


Figure 8. Method of soft start used for impact piling between 2011 and 2021.

Most soft starts for impact piling between 2011 and 2021 met the required minimum duration (usually 20 minutes, but for one O&G project a 10 minute duration was agreed with JNCC). Standards were higher for OWF projects than O&G projects (Table 12). Where soft starts were inadequate on O&G projects, this was often due to there being no soft start; on 12% of occasions there was no soft start on O&G projects while for OWF projects there was no soft start for just 3% of occasions. For both project types, when there was no soft start, this was almost always when there had been a break in piling, either when continuing to drive the same pile or sometimes for other reasons, but these breaks were longer than the 10 minutes allowed in the guidelines before another soft start is required.

Table 12. Percentage (and sample size) of impact piling soft starts lasting the required minimm duration from the commencement of the soft start until full power.

Year	O&G	OWF
2011	90.9 (11)	-
2012	72.4*(29)	-
2013	66.7(3)	-
2014	97.0 (33)	-
2015	78.3 (46)	100 (14)
2016	61.7 (37)	93.5 (155)
2017	96.8 (31)	87.1 (70)
2018	77.8 (18)	100 (11)
2019	-	94.1 (17)
2020	100 (27)	100 (32)
2021	-	92.3 (143)
Total	81.0 (258)	93.0 (442)

* Includes one occasion where a 10-minute soft start was agreed with JNCC

The mean duration of the soft start on O&G projects was 28 minutes and for OWF projects was 31 minutes. The JNCC piling guidelines do not specify a recommended maximum duration for the soft start, but on some occasions soft starts were prolonged. On O&G projects, 10% of soft starts exceeded one hour in duration and 2% exceeded two hours (maximum duration 2 hours 28 minutes), although the majority of these were occasions where hammer energy continued to increase throughout the process of driving the pile. Although many soft starts on OWF projects were slightly longer than those of O&G projects (36% were more than 40 minutes compared to 18% for O&G projects), there was only one occasion when the soft start exceeded one hour (1 hour 12 minutes).

Some reports included graphs of the hammer energy throughout individual pile installations. These showed that the increase during the soft start was not always uniform, nor was there a consistent pattern of hammer energy levels throughout the remainder of installations. In some cases, energy levels increased during the soft start and then remained relatively constant, while in other cases energy levels went up and down throughout the installation. In some cases, there was a steady increase throughout, with some MMO reports noting that the energy level continued to increase after the soft start (in one case there was little increase in energy levels during the soft start, but energy levels increased afterwards).

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

- Soft starts being unable to be carried out after breaks in piling of more than ten minutes due to equipment limitations and/or ground conditions.
- Human error (e.g. recording a break as less than 10 minutes when it was actually longer).
- Misunderstanding between the mitigation team and the crew.
- Confusion due to the crew using the term “soft start” for an engineering soft start and therefore confusing this with the soft start required for mitigation.
- Communication problems between crew.
- Operational constraints preventing a soft start during re-strike tests.
- Hammer power reaching operational levels in less than 20 minutes due to the hard substrate.
- Technical issues with the hammer computer.

The JNCC guidelines say that if a marine mammal enters the mitigation zone during the soft start, then piling should cease, or at least power not increase, until the animal has been gone from the mitigation zone for 20 minutes. There were two occasions when the soft start was stopped due to marine mammals entering the mitigation zone, both on the same OWF project and both involving grey seals. One occurred when piling had already been delayed due to a grey seal in the mitigation zone, but a grey seal appeared in the mitigation zone just two minutes after the soft start commenced after the delay (the report does not give any indication as to whether this was likely to be the same or a different seal). The soft start was stopped and recommenced 24 minutes later. On the other occasion the soft start was stopped due to a grey seal which similarly appeared in the mitigation zone two minutes after the soft start had commenced, and the soft start resumed 21 minutes later.

Many MMO reports noted that due to the nature of the substrate, once piling operations have commenced it is not technically feasible for piling activities to be halted or delayed should marine animals be detected within the mitigation zone, as this could impact the integrity of the piled foundation. These reports noted that once piling operations had commenced, they were to continue, and if marine animals moved into the 500m mitigation zone they would be deemed to have done so “voluntarily”. However, other than the two occasions noted above, there were no occasions when marine mammals were recorded in the mitigation zone during the soft start.

3.3.8 Breaks in operations

In 2011–2021, there were 45 occasions when there was a break in piling of more than 10 minutes, 29 on O&G projects and 16 on OWF projects. For O&G projects there was an adequate pre-piling search before piling recommenced for 27 (93%) of the 29 breaks. On one O&G project, the MMO report stated that searches were only to be done for breaks of more than 30 minutes, although in practice searches were continuous so were done for most breaks. For OWF projects there was an adequate pre-piling search for 13 (81%) of the 16 breaks.

One MMO report from an OWF project that did not submit usable data did report using soft starts after breaks of more than 10 minutes. However, for projects that submitted usable data, there were only two occasions on an OWF project when there was a soft start following a break in piling. For all other occasions on both O&G and OWF projects, piling resumed after a break without a soft start. The maximum duration of a break after which piling resumed with no soft start was 1 hour 3 minutes for OWF projects and 3 hours 33 minutes for O&G projects. Two OWF projects had mitigation protocols that only utilised a soft start after a longer break, of 1 or 2.5 hours respectively, although ADDs were to be deployed for breaks depending on their duration. Some MMO reports noted that having to repeat the soft start procedure on a partially driven pile could affect the long-term integrity of the pile, while some noted that a soft start could not be conducted for operational reasons, in one case due to the hard seabed. In one case, to avoid having to repeat mitigation procedures, a single hammer blow was struck nine minutes after piling stopped during a break of 13 minutes.

Four of the OWF projects where ADDs were used required the ADD to be activated if there was a break of more than 10 minutes, although on one project this was later extended to one hour. Where data were available, all complied with these requirements. For the fifth OWF project where an ADD was used, the MMO report did not specify whether ADDs were to be activated during breaks in piling, but no breaks in piling were recorded on that project, although data were missing for most of it.

There were eight breaks of up to 10 minutes duration. Two of these breaks were during the soft start and the soft start continued after the break. In all other cases piling resumed at full power. In all cases, the search that had started earlier continued throughout the break (in one case using PAM as the break was at night). The guidelines do not address what should happen if a marine mammal enters the mitigation zone during a short break and most projects did not consider what course of action should be taken in this eventuality. For one OWF project, the MMO report said that any marine mammal entering the mitigation zone during a break of less than 10 minutes would be deemed to have done so voluntarily and the crew would be informed and could decide whether to delay or proceed. There were no occasions when marine mammals were recorded in the mitigation zone during a short break.

3.3.9 Piling at night or in poor conditions

Piling started at night on 29% of occasions for O&G projects and 37% of occasions for OWF projects (Figure 9). There were six O&G projects where the licence required PAM to be used at night. On one further O&G project, the MMO report noted that commencing piling at night was discussed with JNCC beforehand and an agreement was gained that piling could commence at night if PAM was used. For other projects, it is not known whether there was any agreement that piling could commence at night.

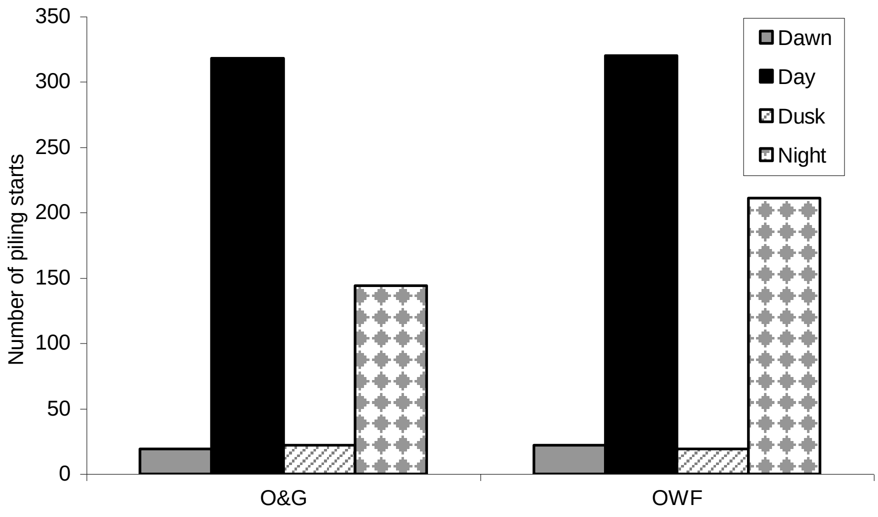


Figure 9. Number of times piling started at different times of day.

When piling started at night, O&G projects used PAM on most occasions (Table 13). One O&G project also requested night-vision binoculars to be available as a back-up to PAM to confirm any acoustic detections visually, but it is not clear whether these were used. There was also one O&G project that used night-vision binoculars at night instead of PAM on logistical and cost grounds (PAM would have required a separate vessel); there were no sightings on that project. For OWF projects, the more common approach at night was to rely on ADDs; however for some projects where PAM was available this was used instead. There was one OWF project where night-vision binoculars were used together with PAM, but no usable data were submitted for that project and the report does not say whether any marine mammals were detected with the night-vision binoculars. For both O&G and OWF projects, there were a few occasions when piling started at night with no mitigation other than a soft start. However, there was one O&G project where piling was delayed until daylight on one occasion because there was no mitigation at night.

Table 13. Mitigation used when piling commenced at night (n = number of occasions when piling commenced at night).

Industry	PAM	ADD	PAM + ADD	Night vision binoculars	No mitigation	n
O&G	131	0	0	3	10	144
OWF	74	131	0	0	6	211

There were 36 occasions when piling was known to have started during poor conditions in daylight hours: 26 during O&G projects and 10 during OWF projects (these are minimum figures as there were also 34 occasions during O&G projects and 59 during OWF projects where weather conditions could not be obtained from Effort data). On O&G projects, PAM was used in addition to visual monitoring on eight of these occasions and instead of visual monitoring on one occasion, while the others relied on visual monitoring only. For OWF projects, ADDs were used together with visual monitoring in all cases.

3.3.10 Variations from the standard protocol

There were four projects where variations from the standard piling mitigation protocol represented an easing of mitigation measures. On one O&G project, it was agreed with JNCC that the mitigation zone would have a radius of 250 m and the soft start would have a minimum duration of 10 minutes. On one OWF project, following consultation with the regulator the pre-piling search was shortened to 25 minutes and delays would only be enacted for marine mammals within a 50m injury zone. On another OWF project, the Marine Mammal Mitigation Plan that was agreed with the regulator said that in the event of a marine mammal occurring in the mitigation zone piling would be delayed for 15 minutes and that a soft start would only be required following a break in piling if the break lasted longer than one hour.

One OWF project employed a phased mitigation plan where, for the majority of the eight-month project, a 60m mitigation zone was applied (based on a predicted injury zone), although there was no requirement to delay piling if a marine mammal occurred in this zone. Mitigation comprised the use of an ADD and soft start without MMOs or PAM, on the assumption that use of the ADD and soft start would cause any marine mammal to flee. Another difference from the JNCC guidelines was that mitigation procedures (15 minutes ADD use followed by a 20-minute soft start) were only required to be repeated if there was a break in piling of greater than 2.5 hours. For breaks between 10 minutes and 2.5 hours, the ADD was required to be deployed for 10 minutes but there was no requirement for a soft start. However, for seven days in the middle of the project, JNCC guidelines were required to be followed (MMO and PAM 30 minute pre-piling search, delay for any marine mammal detected in a 500m mitigation zone, 20 minute soft start, search and soft start repeated after any break of more than 10 minutes), with the ADD only being used at night or in poor visibility. For the subsequent seven days, a combination of JNCC guidelines and the amended protocol was used: MMO and PAM 30 minute pre-piling search including 15 minutes ADD use, delay for any marine mammal detected in a 60m mitigation zone, 20 minute soft start, breaks between 10 minutes and 2.5 hours required 10 minutes ADD activation and a delay for any marine mammal in the 60m mitigation zone, breaks of more than 2.5 hours required all mitigation procedures to be repeated. Following seven days of implementation of JNCC guidelines and seven days implementation of the combined protocol, mitigation reverted to ADD and soft start only for the remainder of the project. This project required data collected during the JNCC guidelines and combined protocol periods to be submitted to the regulator on the Marine Mammal Recording Forms accompanied by an MMO report. However, there was no MMO report, operational and effort data were missing, and sightings data did not include a range to the marine mammals detected (although sightings data included sightings from outside these periods, mostly sightings whilst in transit or incidental sightings on site whilst setting anchors or waiting on weather). As there was no operational data and no range, and no routine monitoring during implementation of the ADD and soft start only protocol, it was impossible to tell whether there were any occasions when piling started with marine mammals in the mitigation zone when a delay would have been implemented had JNCC guidelines been followed throughout.

In some other cases, measures were implemented that were more precautionary than the JNCC guidelines. For one OWF project, the mitigation zone was increased to 690m in the Marine Mammal Mitigation Plan, and for one O&G project it was increased to 1km as part of the consent. There was also one O&G project where the Marine Mammal Mitigation Plan proposed that the mitigation zone was extended to 1km for harbour porpoise, although no porpoises were detected.

On one O&G project, as best practice a decision was made to carry out 60 minutes of observations prior to piling. On this project, the client also requested that MMOs with at least three years of experience were used.

One OWF project had an additional measure for minke whales: if a minke whale was observed within the mitigation zone during daylight hours then piling would not be allowed to commence during the following night or if visibility decreased to a point where visual detection was no longer possible. No minke whales were seen during that project.

3.4 Response of marine mammals to piling

3.4.1 Detection rates in relation to piling activity

Very few marine mammals were detected when impact piling was underway. Only two cetacean sightings (one of a fin whale and the other of long-finned pilot whales with a Risso's dolphin) and three seal sightings occurred during periods of impact piling. In the case of cetaceans, both sightings encountered during piling had been present prior to piling commencing and were still visible outside the mitigation zone when piling commenced; no cetaceans were first detected when impact piling was already underway. The three seals seen during piling appeared when piling was already underway, one grey seal and one unidentified seal whilst piling at full power and one grey seal during the soft start. A further two grey seals were reported as appearing during the soft start on another project but no data to support this were submitted.

Although sample sizes were low, detection rates of grey seals and the combined groups of all seals, all cetaceans and all delphinids were significantly reduced during periods of impact piling compared to when piling was not ongoing (Table 14). However, some of the marine mammals encountered when piling was not ongoing were seen within the hours after impact piling finished on the same day, usually at least four hours after piling stopped, although an unidentified seal and a fin whale were seen within one hour of piling stopping (

Table 15). There was no evidence of a general decline in cetacean detections after impact piling commenced on a project, although the sample size was again low (Table 16).

There were no marine mammal detections while vibratory piling was underway so comparisons were not possible. However, marine mammals were sometimes seen within an hour of piling stopping (

Table 15).

Seals were detected when pile drilling was underway and for this type of piling there was no significant difference in detection rates of grey seals or the combined group of all seals between periods of piling and not piling (Table 14). As well as being seen during piling, those seals seen when not piling sometimes appeared only a short time after piling stopped (

Table 15).

Table 14. Marine mammal detection rates in relation to piling activity, tested using the Wilcoxon signed ranks test (T^+ = sum of ranks of pairs where detection rate when not piling exceeded detection rate when piling; n = number of matched pairs of detection rates at different activities; d.f. = 1). Significant results are in bold.

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Not piling	Piling	T^+	n	p-value
Impact piling					
All seals combined	*0.78* 1.53 2.06	*0.00* 0.00 *0.00*	28	7	**0.008**
Grey seal	*0.78* 1.19 *2.07*	*0.00* 0.00 *0.00*	21	6	**0.016**
All cetaceans combined	*0.28* 0.45 *1.05*	*0.00* 0.00 *0.00*	91	13	**< 0.001**
All delphinids combined	*0.35* 0.50 *0.59*	*0.00* 0.00 *0.00*	15	5	**0.031**
Pile drilling					
All seals combined	*0.00* 0.23 *0.36*	*0.00* 0.00 *0.26*	13	6	0.344
Grey seal	*0.00* 0.33 *0.36*	*0.00* 0.00 *0.26*	9	5	0.406

Table 15. Minimum time recorded until next sighting after an episode of piling.

Species	Impact piling	Vibratory piling	Pile drilling
Unidentified seal	0hr 45m	0hr 23m	0hr 10m
Grey seal	5hr 58m	0hr 05m	0hr 10m
Harbour seal	7hr 25m	-	-
Unidentified cetacean	5hr 29m	-	-
Fin whale	0hr 55m	-	-
Minke whale	5hr 31m	-	-
Long-finned pilot whale	6hr 48m	-	-
Killer whale	9hr 02m	-	-
Unidentified dolphin	8hr 19m	0hr 07m	57hr 59m
Risso's dolphin	11hr 54m	-	-
Bottlenose dolphin	-	0hr 29m	-
White-beaked dolphin	63hr 26m	-	-
Atlantic white-sided dolphin	6hr 25m	-	-
Common dolphin	-	-	-
Harbour porpoise	4hr 45m	-	-

Table 16. Marine mammal detection rates prior to piling first commencing on a project compared to after piling commenced, tested using the Wilcoxon signed ranks test (T^+ = sum of ranks of pairs where detection rate prior to piling first commencing exceeded detection rate after piling commenced; n = number of matched pairs of detection rates prior to and post piling commencing; d.f. = 1).

Species	Median detection rate per hour (+ 1st and 3rd quartiles) Prior to commencing	Post piling commencing	T^+	n	p-value
Impact piling					
All cetaceans combined	*0.00* 0.07 *0.17*	*0.00* 0.02 *0.13*	29	9	0.248

3.4.2 Closest distance of approach to the pile (piling versus not piling)

During impact piling, seals were mostly seen when piling was not taking place, only occasionally being seen while piling. They remained significantly further from the pile while impact piling was being conducted compared to when piling was not ongoing (Table 17), although the few that were seen during piling were all within 1km of the pile (Figure 10). The only cetaceans seen during impact piling were those that were already present prior to piling and therefore could not be used to compare the closest point of approach.

During pile drilling, seals were seen more often but there was no significant difference in their closest approach to the pile when piling was underway (Figure 11, Table 17). No cetaceans were seen whilst pile drilling was underway and no marine mammals of any kind were seen whilst vibratory piling was underway.

Table 17. Closest distance of approach of marine mammals to the pile in relation to piling activity, tested using the Wilcoxon-Mann-Whitney test (W_x = sum of ranks of the smallest group; z = Wilcoxon statistic for large samples; n = sample size; d.f. = 1). Significant results are in bold.

Species	Median closest distance (metres)		W_x	z	n	p-value
	Not piling	Piling				
Impact piling						
All seals combined	60	700	110.5	1.982	44	**0.024**
Pile drilling						
All seals combined	250	200	192	0.918	30	0.179
Grey seal	250	200	126	1.127	23	0.129

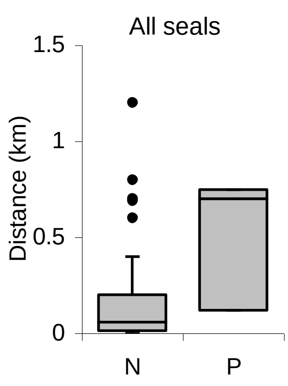


Figure 10. Box-and-whisker plots of closest distance of approach to the pile relative to impact piling activity (N = not piling; P = impact piling). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers and dots show outliers (> 1.5 x interquartile range outside the 1st or 3rd quartile).

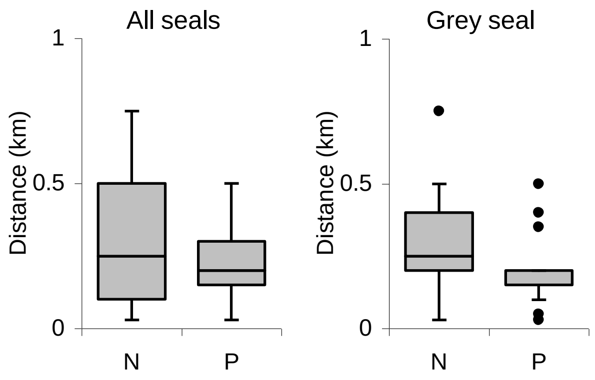


Figure 11. Box-and-whisker plots of closest distance of approach to the pile relative to pile drilling activity (N = not piling; P = pile drilling). Boxes show median, 1st and 3rd quartiles, whiskers denote range excepting outliers and dots show outliers (> 1.5 x interquartile range outside the 1st or 3rd quartile).

3.4.3 Behaviour

Very few marine mammals were encountered during periods of piling other than seals during pile drilling, which took place on one project in a coastal location. Significantly fewer seals (all species combined) were hauled out when pile drilling was occurring (Table 18). Although more seals were travelling away from the piling platform or showing avoidance during piling compared to periods of not piling, the difference was not significant. The report for the project where pile drilling was used noted that, “Grey seals seemed to observe the activities around the barge and were often seen to be surfacing and looking in the direction of the barge”. Sample sizes were not sufficient to test other behaviours during pile drilling, or any behaviours during impact or vibratory piling.

Table 18. Behaviour of marine mammals in relation to pile drilling activity, tested using the chi-squared test (n = number of sightings where the behaviour was exhibited; d.f. = 1). Significant results are in bold.

Behaviour	**Species**	**Frequency (and %) of encounters when behaviour was exhibited**				**χ^2**	**n**	**p-value**
		Not piling		**Piling**				
Avoidance or travel away from vessel / equipment	All seals combined	5	(25.0%)	9	(42.9%)	0.96	14	< 0.50
Hauled out	All seals combined	9	(45.0%)	2	(9.5%)	4.81	11	**< 0.05**

There were nine sightings of marine mammals when ADDs were active; five were first seen before the ADDs were switched on and were still present as it was activated but four appeared after the ADD had been activated. Of those animals that were encountered before the ADD was activated, most disappeared shortly after activation; those that remained for longer after activation were already outside the mitigation zone before the ADD was activated (Table 19). However, in only two encounters (both grey seals) were animals observed to be actively swimming away after the ADD was activated, and one of these initially swam towards the active ADD and came to a distance of just one metre from the pile before swimming away.

On two of the four occasions when animals appeared when the ADD was already active, the animals (an unidentified cetacean, suspected to be a minke whale, and a pod of three harbour porpoises) appeared some distance away (Table 20). On the other two occasions, the animals (both seals) appeared close to the pile. One unidentified seal appeared only briefly, but a harbour seal remained in the mitigation zone for 51 minutes and was undeterred, resulting in a delay to piling. It was recorded as approaching the monopile several times and trying to climb it while the ADD was active (Figure 12 shows the seal in contact with the pile). It was recorded as eventually adopting a bottling position (Figure 13) and drifting away. It was noted that the seal's head was above water for much of the encounter. While all other animals appearing after the ADD was activated were first seen shortly after activation (so were potentially already in the area but undetected prior to ADD activation), this harbour seal first appeared when the ADD had already been active for some time. Of the four sightings that appeared after the ADD was activated, only the harbour porpoises were recorded as swimming away from the vessel.

Only 10% of the time spent monitoring during impact piling was during the soft start. There were four sightings during the soft start of impact piling. Two were of individual grey seals in the mitigation zone, both on a project where no data were submitted, although the MMO report records that the soft start was stopped on both occasions. These seals were seen at 100m and 350m from the pile. In each case, the seal was seen two minutes after the soft start had commenced and was visible for less than one minute. The other two sightings were outside the mitigation zone. One, a group of long-finned pilot whales with a Risso's dolphin, was first encountered prior to the soft start and was still visible briefly after the soft start commenced, the soft start having been delayed until 20 minutes after the last detection in the mitigation zone. These animals were recorded as swimming slowly in variable directions. The other sighting, of a grey seal, occurred 17 minutes into the soft start; the seal was spotted 750m from the pile by a crew member on board a noise monitoring vessel and was seen briefly swimming at the surface.

Table 19. Marine mammals detected prior to ADD activation where the ADD was activated during the encounter.

Species	Time of appearance before ADD activation (minutes)	Time of disappearance after ADD activation	Behaviour
Seal sp.	1	3	Milling at surface, feeding on fish. In mitigation zone when ADD activated. Variable direction of travel.
Grey seal	9	< 1	Milling around pile, feeding. In mitigation zone when ADD activated. Variable direction of travel.
Grey seal	21	5	Resurfaced in mitigation zone 3 minutes after ADD activated. Swimming at surface towards ADD then around pile and away from vessel. Closest approach 1m from pile while ADD active.
Grey seal	28	16	Initially milling at surface between dives. Left mitigation zone 13 minutes before ADD activated, swimming away after ADD activated.
Harbour porpoise	30	8	Surfacing, travelling. Closest approach 2km from pile before ADD activated.

Table 20. Marine mammals encountered during ADD use, where initial detection was after ADD activation.

Species	Time of appearance after ADD activation (minutes)	Duration of sighting (minutes)	Behaviour
Seal sp.	6	1	Bottling, dived. Appeared 250m from pile.
Harbour seal	27	51	Remained in vicinity of vessel, not deterred by ADD. Approached pile, tried to climb pile. Eventually adopted bottling position and drifted away.
Cetacean sp.	< 1	< 1	Fin seen briefly at time of ADD start. Appeared 1.8km from pile.
Harbour porpoise	5	12	Surfacing, travelling. Appeared 2km from pile. Travelled away from vessel.

Figure 12 Photograph from an MMO report showing a harbour seal in contact with a pile while an ADD was active.

Figure 13 Photograph from an MMO report showing the harbour seal adopting a bottling posture during ADD activation.

4 Discussion

4.1 Submission and quality of data

Submission of MMO reports and data for O&G projects was generally good. For many of those where there was no submission, it appeared that mitigation may not have been included in the licence. It is therefore recommended that licences clarify the requirement for mitigation when undertaking piling operations.

Submission of reports and data for OWF projects was poor. Unlike O&G, OWF projects are managed by different regulators depending on location, so there was no central repository for post-mitigation reports or data. Ensuring that all reports and data are submitted to JNCC as well as the regulator would improve collation of data for future analysis. Recording forms were missing for OWF projects more often than MMO reports; only four of 25 OWF projects submitted both an MMO report and Excel recording forms. There were several issues with submissions for OWF projects, which could be summarised as: no submission at all; recording forms missing; MMO report missing; information missing for the majority of the project; data submitted as a pdf rather than Excel file; and summary data (lacking detail) included in tables in the MMO report in lieu of the recording forms. In the latter case, the current design of the marine mammal recording forms being primarily aimed at geophysical surveys may have deterred some observers from using them.

There is a need for recording forms designed specifically for piling that would facilitate recording relevant information such as the type of piling, the size of hammer, the maximum energy used for each piling session and the timing of the use of ADDs. 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.

Where data were submitted on recording forms these were mostly usable but still required corrections to be made. Many of the errors could have been avoided with more care and careful checking by MMOs and PAM operators. Careless mistakes such as wrong dates and errors in whether positions were east or west of Greenwich suggest that mitigation personnel sometimes do not check their data. Checks should also 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.

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 real 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 piling operations 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 operations. 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 locations but were also seen further offshore. Grey seals were seen further offshore than harbour seals, particularly in the northern North Sea, corresponding with studies of tagged seals of both species (Carter *et al.* 2020). Grey seal foraging trip duration and extent has been found to have increased while that of harbour seals has decreased (Russell 2015).

The harbour porpoise is one of the most abundant cetaceans in European Atlantic waters (Hammond *et al.* 2021) and was the cetacean species recorded most often during piling projects. 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 southwards shift in distribution of harbour porpoises in the North Sea, extending into the English Channel by 2016 (Hammond *et al.* 2021); it was the only species recorded during piling operations in the English Channel.

Minke whales were widespread throughout the North Sea and also in deeper waters, which concurs with their known distribution (Reid *et al.* 2003; Hammond *et al.* 2013, 2021). Some occurred closer inshore, particularly in the Moray Firth, where near shore feeding aggregations are known to occur in late summer (Reid *et al.* 2003).

Other species were only seen in low numbers, but the distribution of sightings again largely concurred with known distribution. Fin whales, long-finned pilot whales and Atlantic white-sided dolphins 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 piling projects to 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), particularly in the Moray Firth, where most bottlenose dolphins seen during piling projects were found.

There were only two sightings of Risso's dolphins; this species is distributed mainly on the continental shelf (Reid *et al.* 2003; Hammond *et al.* 2021) but one of the two sightings was in deeper waters. Common dolphins have a predominantly south-western distribution in UK waters (Reid *et al.* 2003; Hammond *et al.* 2013, 2021) but there were no piling projects in the south-west. The single sighting of a common dolphin occurred in the southern North Sea, where there have been occasional sightings previously (Reid *et al.* 2003).

4.3 Compliance with guidelines

4.3.1 Noise abatement

The JNCC piling guidelines recommend that developers demonstrate they are using best available technique to provide a high level of environmental protection. There was little attempt to reduce noise during the piling projects reported here. Vibratory piling produces lower levels of noise compared to impact piling (Tsouvalas & Metrikine 2016; Tsouvalas 2020), but it is unclear whether the few projects that used vibratory piling were doing so in order to reduce noise or for operational reasons. Similarly, it was unclear whether the project that replaced a steel cushion with a plastic one did so for the purpose of reducing noise, or whether it was to reduce stress on the pile and the noise reduction was an incidental benefit.

Noise abatement systems such as big bubble curtains, casings and resonators have been used for OWF construction in other countries, mainly in Germany but also in Belgium and Denmark (Verfuss *et al.* 2019). Although a resonator has been tested during construction of one OWF in UK waters (Elmer & Savery 2014; a project for which no MMO report or data were received), the use of noise abatement systems has not been widely adopted by the OWF industry in the UK. Such systems have been found to reduce broadband sound levels by about 10 dB (Elmer & Savery 2014; Brandt *et al.* 2016; Verfuss *et al.* 2019). Some variability has been noted, probably due to differences in combinations of systems, their efficiency at the time and environmental factors affecting sound propagation (Brandt *et al.* 2016).

4.3.2 MMOs and PAM operators

OWF projects used slightly higher numbers of personnel overall, being more likely to have a team of two dedicated MMOs even if PAM was not used. O&G projects were more likely to use just one dedicated MMO, although often there was also a PAM operator. The number of personnel on a mitigation team may be linked to the duration of the project and thus the perceived need for mitigation personnel. O&G projects tended to have fewer piles to install and were of shorter duration, while OWF projects tended to have more piles to install and were of longer duration. However, it is important that number of personnel is considered in terms of a daily requirement, as illustrated by the O&G project where a lack of breaks for the MMO during one day was reported. Use of a single dual role MMO / PAM operator, as happened on three O&G projects, should not continue as it is unrealistic to expect one person to cover both roles, even if the project is of short duration.

4.3.3 Use of PAM

PAM was always used where it was a condition of the licence. It was used more often on O&G projects than OWF projects, which tended to rely more on the use of ADDs to deter animals at night rather than PAM to detect them. However, where PAM was used, it was more likely to be used by day as well as at night for OWF projects, while O&G projects used PAM mostly just at night.

The reason for the complete absence of acoustic detections is unclear. Excessive background noise was noted as an issue in some reports, which could have made it difficult to detect vocalisations, particularly from more distant animals. The general noise around the construction sites may also have deterred animals from the vicinity, leading to a lack of detections particularly for the harbour porpoise, whose high frequency clicks are only detected within a range of around 400m (Cucknell *et al.* 2016). Visual detections were more often of seals than cetaceans, but seals do not reliably vocalise underwater and therefore PAM is not an appropriate method of detection (Herschel *et al.* 2013). Similarly, minke whales do not reliably vocalise and PAM is again regarded as an unsuitable method of detection (Herschel *et al.* 2013). However, other cetaceans were detected visually with some (including harbour porpoises) being detected at close range, yet none were detected acoustically. An earlier study of OWF construction preceding the projects reported here also found there were no acoustic detections, although very limited data were available (SMRU 2009). Reduced acoustic detection rates compared to visual detection rates have also been found with PAM used for mitigation on geophysical surveys (Stone 2023a).

4.3.4 The pre-piling search

Although most visual pre-piling searches in daylight were of adequate duration, there was room for improvement. Where searches were inadequate it was usually because there was no search rather than the search not being long enough, and this was mainly due to switching to PAM instead of a visual search even though conditions were sometimes still adequate for visual monitoring. Where PAM was used, acoustic searches at night were always of adequate duration. Where PAM was available on OWF projects, it was usually also used in daytime, but often at the expense of visual monitoring. On O&G projects, PAM was not often used in daytime.

Compliant pre-piling searches were assessed as those that met the required duration specified in the JNCC guidelines. Currently the guidelines require that the search is conducted for at least 30 minutes prior to the commencement of piling. There is no requirement that the search continues throughout the soft start, even though there is a requirement to stop the soft start (or at least no further increases in power) if a marine mammal enters the mitigation zone during the soft start. Clearly then it would be appropriate to continue monitoring throughout the soft start, but as this is not currently a stated requirement in the guidelines, and most MMOs / PAM operators recorded the end time of the search on the Operations form as the time when the soft start began (even though they may have continued monitoring), this has not been assessed.

In the past, MMOs on OWF construction projects have often been based on separate survey vessels (SMRU 2007; Herschel *et al.* 2013; Coram *et al.* 2014). Although this was still the case for a few of the projects reported here, in most cases MMOs were on the installation vessel, particularly in recent years. As well as being more cost-effective, it also ensures that the mitigation personnel are always present to conduct a pre-piling search whenever it is needed and provides for effective communication with the piling crew.

Monitoring with MMOs can only provide mitigation for injury in the near field, therefore may be less effective where injury zones are large, for example with larger diameter piles (Herschel *et al.* 2013). In these cases, the use of noise abatement to reduce predicted injury ranges would be beneficial in making monitoring more effective as a mitigation measure as well as directly reducing the risk of injury.

4.3.5 Acoustic deterrent devices

Varying durations were given for ADD deployment on OWF projects, ranging between 15 and 30 minutes. In one case where the deployment was 15 minutes, it was known that this was based on estimates of the size of the impact zone and likely swimming speeds; in other cases it was not known how the duration was determined but it seems likely that similar methods were used.

Although ADD use was generally compliant, there were some areas where improvements could be made. On some occasions there was a gap between the ADD being deactivated and the soft start beginning. In order to maintain any deterrent effect, the ADD should continue until the soft start begins. Given that deployment durations were only between 15 and 30 minutes, a gap of up to eight minutes (the maximum gap recorded) between ADD use and the soft start could potentially allow animals to return some distance. Although it seems unlikely that an animal that had been deterred would immediately return, based on a conservative swim speed of $1.5ms^{-1}$ as used by Herschel *et al.* (2013), a harbour porpoise could potentially travel 720m in eight minutes.

The current guidelines say that ADDs should only be used in conjunction with visual and/or acoustic monitoring, but this was often not the case. There was never acoustic monitoring when ADDs were used at night. One project had an agreed phased mitigation plan where ADDs would be used as a substitute for monitoring; it seemed that other projects also adopted this strategy at night, although as licences were not seen it is not known whether this was agreed with the regulator.

When there was visual monitoring before the use of ADDs, ADDs were sometimes activated when marine mammals were in the mitigation zone or shortly after. The current guidelines give no guidance about what to do if a marine mammal is seen prior to ADD activation. Similarly, there is no guidance about what to do if a marine mammal is seen during ADD use. Given the potential for auditory impairment (Findlay *et al.* 2022) it might have been prudent to stop the use of the ADD for the harbour seal that remained undeterred in the mitigation zone for 51 minutes during ADD use.

4.3.6 Delays in operations

Delays were enacted on all but two occasions when they were required. One of the occasions when there was no delay highlights the importance of effective communications, as the MMOs thought piling had finished so they did not inform the crew of the presence of a seal, when in fact it was just a break in piling. MMOs / PAM operators and crew both have a responsibility to ensure there are effective communication channels so that mitigation personnel are aware of activities and are thus able to provide mitigation advice when needed.

On one project, the Marine Mammal Mitigation Plan interpreted the guidelines differently from the way they are usually interpreted, allowing the soft start to commence as soon as animals had been tracked outside of the mitigation zone, resulting in three occasions when the delay was substantially shorter than 20 minutes. The guidelines say, “Piling should not be commenced if marine mammals are detected within the mitigation zone or until 20 minutes after the last visual or acoustic detection. The MMO and PAM operative should track any marine mammals detected and ensure they are satisfied the animals have left the mitigation zone before they advise the crew to commence piling activities.” This is usually interpreted as waiting 20 minutes after the last detection of the animal in the mitigation zone, in line with the requirements of the JNCC guidelines for geophysical surveys and the use of explosives, where the wording is less ambiguous. This 20 minute period acts as a buffer to ensure the animals have left the zone and are not simply invisible below the surface in the zone. It is perhaps particularly important for seals, which have a tendency to move unpredictably below the surface and will often linger around something that arouses their curiosity.

4.3.7 The soft start

One of the main issues with the soft start, encountered in several projects, was its absence following a break in piling of more than 10 minutes, where the guidelines require the soft start to be repeated. Aside from these instances, most soft starts met the recommended minimum duration specified in the guidelines.

The guidelines describe the soft start as a gradual ramping up of piling power incrementally over a set time period of not less than 20 minutes. A maximum duration is not specified, but some soft starts were prolonged. However, as hammer energies seemed to vary during individual installations, it was not clear whether this was just a consequence of a lower energy being needed to drive the pile. Furthermore, it seems likely that there is some variation in the point at which the soft start is regarded as completed as in some cases the energy continued to increase after the time recorded as the end of the soft start. Thus, it is not clear to what extent, if at all, a longer soft start prolonged piling operations and increased overall noise input to the marine environment. A maximum duration of the soft start is probably unnecessary and could be difficult to implement. It is more important that the minimum duration is adhered to, so that there is a gradual increase at the start of piling allowing animals time to move away, although often the increase was not uniform.

Although some reports noted that stopping activities once piling had started was not technically feasible as it could affect the integrity of the piled foundation, on two occasions when marine mammals were seen in the mitigation zone during the soft start, piling ceased. The guidelines do allow an alternative to stopping, which is not to increase the energy any further; this approach was not used, and no comments were received on the feasibility of this option.

The assumption behind the soft start is that lower hammer energies will produce lower noise levels. However, outside of very shallow waters the situation may be more complex. Thompson *et al.* (2020), studying an installation of jackets with pin piles in waters of 45m depth, found that received noise levels were highest at the beginning of a period of piling when hammer energy was lower, as the predominant influence was a strong negative relationship with penetration depth; when most of the pile was in the water column during the soft start period a higher proportion of hammer energy was converted into waterborne acoustic energy. They suggested that soft starts could be improved by having an extended initial phase of piling at low blow rates and also further reducing the hammer energy during these initial strikes. OWF projects included an increase in blow rate together with an increase in energy as part of the soft start more often than O&G projects did, although O&G projects tended to be in deeper waters where it would be beneficial to start with a low blow rate.

4.3.8 Breaks in operations

There was often no soft start following a break in piling of more than 10 minutes, even for prolonged breaks (on one occasion, over three hours). Some studies have found that in some cases displacement of marine mammals due to piling operations persists for only a few hours after piling ceases (Tougaard *et al.* 2006b, 2013b; Brandt *et al.* 2018; Geelhoed *et al.* 2018). Potentially animals could be returning to the vicinity, therefore a soft start or some alternative mitigation is necessary following a prolonged break. Some reports commented on the difficulty of performing a soft start with a partially driven pile. Some OWF projects activated an ADD during longer breaks and this could be an alternative where there is a genuine difficulty in performing a soft start following a break.

Although the guidelines recommend another pre-piling search and soft start for breaks of more than 10 minutes, there is no guidance about what to do for shorter breaks. On many projects it was reasonably inferred that piling could resume at full power after a short break. Although not required in the current guidelines, monitoring continued throughout all short breaks. The current guidelines do not address what should happen if a marine mammal occurs in the mitigation zone during a short break, but this situation did not arise. The OWF project where it was left to the crew to decide a course of action should this situation arise illustrates the need for guidance on this.

4.3.9 Piling at night or in poor conditions

Under the standard protocol in the guidelines, piling should not commence at night or in poor visibility or sea states not conducive to visual mitigation (above sea state 4). However, it is recognised that this may be restrictive and variations may be agreed with regulators. Although piling did not start in poor weather conditions very often, approximately one third of piling commenced at night. As licences for most projects were not available for inspection, it was not clear how often variations were agreed to allow piling to commence at night.

Where piling did commence at night, there was a difference in approach between the industries, with O&G projects using PAM whereas for OWF projects ADDs were used almost twice as often as PAM. A similar approach was used for those occasions when piling started in poor weather conditions, with O&G projects sometimes supplementing a visual watch with PAM, but OWF projects using ADDs. However, on one project PAM was sometimes used as a substitute for visual monitoring rather than to supplement it, even during conditions still suitable for visual monitoring and below the threshold proposed for PAM in either the guidelines or the project Marine Mammal Mitigation Plan. Given the lack of acoustic detections on any projects, it is likely that the pre-piling search was compromised on this project by substituting visual monitoring with PAM.

4.3.10 Variations from the standard protocol

Variations from the standard protocol sometimes involved a decrease in the size of the mitigation zone based on the range of predicted injury. For two of the three projects where a smaller mitigation zone was allowed, there is no record of any verification of the predicted injury zone. The third project with a reduced mitigation zone was the OWF project that had a phased mitigation plan, where for most of the project ADDs and soft starts were used in place of monitoring and the mitigation zone was reduced to 60m, based on a theoretical predicted injury zone calculated beforehand. For this project, noise measurements were taken during a late stage of the project; it was reported afterwards that the actual predicted zone of instantaneous injury from the first pile strike was 290m, much greater than was originally thought (Thompson *et al.* 2020). It is not known whether the mitigation zone was changed for the remainder of the project, but as there was no monitoring (and no delays for animals in the mitigation zone) for the remainder of the project and ADD plus soft start duration was sufficient to allow animals to flee to 2-3km (assuming that animals do flee), this would have made no practical difference. However, it does highlight the need for verification of theoretical predicted injury zones.

4.4 Response of marine mammals to piling

Detection rates of cetaceans and delphinids were significantly reduced when impact piling was taking place, suggesting avoidance / displacement. While this result could to some extent be influenced by the requirement to delay piling if marine mammals are close by, the fact that no cetaceans first appeared while piling was underway is also indicative of avoidance. Piling noise is thought to be audible to cetaceans such as bottlenose dolphins and harbour porpoises up to tens of kilometres away (Bailey *et al.* 2010; Kastelein *et al.* 2013b). A number of studies have found avoidance / displacement of harbour porpoises in response to piling noise (e.g. Thompson *et al.* 2010; Brandt *et al.* 2018; Benhemma-Le Gall *et al.* 2021). Observations from MMO data are limited to the immediate vicinity of operations, but in some cases displacement has been found to extend up to 20km away and sometimes beyond (SMRU 2009; Tougaard *et al.* 2009; Dähne *et al.* 2013; Haelters *et al.* 2015; Brandt *et al.* 2016; Geelhoed *et al.* 2018). Tougaard *et al.* (2013a) considered that the effective deterrent range for harbour porpoises during offshore wind farm construction was 26km. The harbour porpoise was the cetacean species most frequently encountered during the piling projects studied herein, but none were seen while piling.

Sample sizes in the present study were too low to permit more detailed examination of any displacement, for example during the hours preceding piling. Studies of harbour porpoises have sometimes shown that detections begin to decline several hours before the start of piling (Brandt *et al.* 2016, 2018; Geelhoed *et al.* 2018), thought to be due to an increase in construction-related activities. However, the occurrence of marine mammals in the mitigation zone on some occasions shortly before piling was due to commence (and thus requiring a delay in piling) indicates that increased activity leading up to piling cannot be relied on to deter animals and confirms a continued need for monitoring.

Exclusion from an area due to displacement, particularly if it is prolonged, may affect vital rates and potentially have population-level consequences (Harwood *et al.* 2014). Although there was some evidence of displacement of cetaceans during active impact piling, there was no evidence of a general decline in the occurrence of cetaceans after impact piling commenced on a project, although data were limited. Some cetaceans (including harbour porpoises) were seen within hours after piling stopped. Booth *et al.* (2017) found that if animals are only disturbed while piling is actually taking place, the aggregate effects of wind farm construction are forecast to be small, even if the maximum number of animals are disturbed on each day of piling. While some studies have found that the effects of piling on harbour porpoises persist for a few hours after the end of each piling operation (Tougaard *et al.* 2006b, 2013b; Brandt *et al.* 2018; Geelhoed *et al.* 2018), other studies have found that the effects may persist for up to a few days (Carstensen *et al.* 2006; Thompson *et al.* 2010; Brandt *et al.* 2011, 2016, 2018; Rose *et al.* 2019). In the German Bight, Brandt *et al.* (2016) found that even though there were short-term negative effects on harbour porpoises there was no indication of negative effects at the population level. However, in some cases effects have continued for some years into the operational phase of offshore wind farms (Tougaard *et al.* 2006a; SMRU 2009; Rose *et al.* 2014), with one case where echolocation activity had not fully recovered nine years into the operational phase (Teilmann & Carstensen 2012).

Responses to piling are not limited to displacement, although the lack of cetacean sightings during piling did not permit examination of other behavioural responses here. Results of playback experiments with harbour porpoises suggest that high-amplitude pile driving sounds are likely to negatively affect foraging in some harbour porpoises by decreasing catch success rate and increasing the termination rate of fish-catching attempts (Kastelein *et* *al.* 2019). Harwood and King (2014) considered that harbour porpoises are probably unable to survive extended periods of behavioural disruption if these affect feeding ability, due to their small size and inability to store large reserves of energy in their blubber. Conversely, Benhemma-LeGall *et al.* (2021) found an increase in porpoise buzzing activity (indicative of foraging) during piling but suggested this may be in compensation for increased noise. Playback experiments have also shown behaviour indicative of mild stress during exposure of porpoises to piling noise, e.g. increased respiration rate, increased swimming speed and increased jumping (Kastelein *et al.* 2013c, 2016). Temporary threshold shift has also been demonstrated (Kastelein *et al.* 2016).

Much of the focus of concern regarding the adverse impacts of piling has been on the harbour porpoise. As a very high frequency cetacean it is more vulnerable to suffering auditory impairment, either temporary threshold shift (TTS) or permanent threshold shift (PTS), than other marine mammal species in UK waters as a result of exposure to impulsive noise (Southall *et al.* 2019). However, seals were observed most often in the projects examined here and are also vulnerable to injury, albeit predicted injury zones will be less than for harbour porpoises. Seals also demonstrated avoidance / displacement in response to impact piling. Detection rates of grey seals and the combined group of all seals were significantly reduced when impact piling was taking place and the few seals that were present at these times were found to remain significantly further from the pile compared to when impact piling was not underway. Most previous studies on responses of seals to piling have focussed on harbour seals. Kastelein *et al.* (2013a) suggested that piling sounds are audible to harbour seals up to hundreds of kilometres away depending on propagation conditions and ambient noise. Harbour seal abundance has been reported to be reduced during piling (Tougaard *et al.* 2006c; Rose *et al.* 2014), in one study at distances up to 25km from the pile location (Russell *et al.* 2016). Fewer seals were found to haul out during piling (Teilmann *et al.* 2006) although Skeate *et al.* (2012) found that only harbour seals were affected and not grey seals, for which numbers hauled out increased. Hastie *et al.* (2015) found that the closest approach of tagged harbour seals to piling varied between 4.7 and 40.5km and suggested that half of the seals were exposed to noise levels that exceeded permanent auditory damage thresholds. In the present study, although seals remained further from the pile during periods of impact piling, the few seals that were present were all within 1km, so potentially were in an area where auditory injury could be possible.

Most previous studies on the response of marine mammals to impact piling have considered individual projects, whereas the results presented here were from a variety of projects (not just wind farm construction) with hammers of different energy, piles of different diameters and in differing locations likely to vary in their depth and substrate. Noise levels have been found to vary with characteristics such as hammer energy and pile diameter (Nedwell *et al.* 2003; Nedwell & Howell 2004; Robinson *et al.* 2007; Nehls *et al.* 2007), although sometimes results are not as expected (Thompson *et al.* 2020). It is likely that source levels and propagation conditions varied considerably between the projects examined here. SMRU (2009) concluded that effects of construction can differ from one wind farm to another depending on the size and type of piles used, the substrate and sound propagation in the water column and the marine mammal species exposed. Whilst the degree of response has been found to be related to noise levels (Rose *et al.* 2014; Brandt *et al.* 2016; Nehls *et al.* 2016), other factors also contribute, e.g. duration of piling (Rose *et al.* 2014) and wind speed (Nedwell *et al.* 2003; Brandt *et al.* 2016). Brandt *et al.* (2016) also considered that the quality of feeding habitat and thus the motivation of animals to remain in an area could account for a difference in response between projects and Geelhoed *et al.* (2018) suggested that location, season, age composition of the local population and adaptability of animals might affect the extent and duration of a response. Factors such as location, season, weather conditions and project specifics like hammer energy and pile diameter were controlled by using a matched pairs approach in the present analysis. Although the relatively low number of sightings limited the scope of the analysis, it is notable that over the whole range of projects the results provided evidence of avoidance / displacement of cetaceans and seals during impact piling.

Noise from vibratory piling is less than that produced by impact piling (Tsouvalas & Metrikine 2016; Tsouvalas 2020). Sample sizes in the present study did not permit analysis of responses of marine mammals to vibratory piling, although no marine mammals were seen while vibratory piling was underway. Graham *et al.* (2017) found that bottlenose dolphins and harbour porpoises were not excluded from sites in the vicinity of vibratory piling, but did find that bottlenose dolphins were in the vicinity for a reduced period and that the probability of occurrence of both species was reduced during periods of piling. They emphasised the need for better understanding of the noise levels and behavioural response to vibratory piling before recommending its use as an alternative to impact piling.

There was no significant avoidance of pile drilling by seals, but seals hauled out significantly less often when pile drilling was underway. Whilst a reduction in numbers of seals hauled out has sometimes been noted for impact piling (Teilmann *et al.* 2006; Skeate *et al.* 2012), no previous studies have examined the response of marine mammals to pile drilling. Teilmann *et al.* (2006) considered that seals may remain in the water during piling rather than haul out on land because it represents a safer environment for them. A reduction in the numbers of seals hauled out during pile drilling is likely to represent some degree of disturbance. Furthermore, there could be energetic costs for seals if they are prevented from hauling out, and are therefore unable to rest, during piling activity. For projects where pile drilling runs continuously for prolonged periods this could have significant consequences for local populations of seals.

ADDs are audible to marine mammals at considerable distances. The Lofitech Seal Scarer, chosen for all five OWF projects that utilised an ADD regularly, is audible to harbour porpoises out to distances between 18km and 91km depending on background noise and propagation conditions (Kastelein *et al.* 2010). It 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. Brandt *et al.* (2013) suggested that deterrent distance could vary between sites due to different transmission loss related to characteristics such as substrate type. 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, with evasive responses up to 7km away, but still there were a few detections heading towards the source. In the present study there were only two harbour porpoise sightings when an ADD was active; both sightings occurred at 2km distance, a distance where deterrence has been recorded in other studies (Brandt *et al.* 2012a, 2012b, 2013; Graham *et al.* 2023), but only one pod was observed to be travelling away from the area. Brandt *et al.* (2012a) considered that there could be differences between individual animals depending on their previous exposure, individual sensitivity and behavioural context. For those animals not deterred they noted that the ADD itself may then pose a risk of hearing damage if the animals stay in close proximity for a prolonged period.

The Lofitech device is also audible to harbour seals out to distances between 17km and 99km depending on background noise and propagation conditions (Kastelein *et al.* 2010). It has 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). Herschel *et al.* (2013), considering the use of ADDs for mitigation, reported a maximum effective deterrent range for pinnipeds of 250m. In the present study, most seals present when the ADD was active disappeared shortly after ADD activation and/or were observed swimming away from the area, although the behaviour in many cases (e.g. variable travel direction, bottling) did not indicate 'fleeing' and one grey seal did approach the ADD as close as one metre from the pile before swimming away. One study on the effectiveness of ADDs for deterring seals from salmon nets found that although seals were deterred, grey seals were more persistent at remaining in the area during ADD use than harbour seals (Harris *et al.* 2014). Sparling *et al.* (2015) also cited anecdotal reports from fish farms that grey seals were not deterred by ADDs as effectively as harbour seals but cautioned against comparing wind farm sites with fish farm sites where there may be motivation for seals to remain. In the present study there was also one harbour seal that appeared in the mitigation zone when the ADD had been active for some time and approached and even tried to climb the pile. It was recorded as having its head above water most of the time, which potentially could have made the ADD less effective. Conversely, its posture with its head above water could have been an attempt to escape the sound of the ADD, as could its attempt to climb the pile; Kastelein *et al.* (2017a) found that harbour seals sometimes spent more time with their head above water, hauled out more often and jumped more in response to an ADD. However, in the case of the harbour seal in the present study, given that the seal appeared in the mitigation zone after ADD activation and remained there for 51 minutes it seems more likely that it was not deterred in any way by the ADD and was perhaps even attracted by the sound. 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 than during control periods and suggested that the sound could elicit curiosity rather than fear in seals. As most (but not all) harbour porpoises in their study showed avoidance when exposed to the same sound, they concluded that to use an ADD with a signal that would deter seals could constitute a disproportionately large habitat loss for harbour porpoises.

There is potential for habituation to ADDs, as has sometimes been found for harbour seals (Jacobs & Terhune 2002; Gotz & Janik 2010). Gotz and Janik (2013) noted that while habituation to ADDs seemed to be commonplace in pinnipeds, it was not in odontocetes. Seals may habituate to ADDs used as a deterrent at fish farms due to the attraction of a food source, whereas habituation may be less likely for ADDs used as mitigation for piling, as any association of the sound would be with negative reinforcement, i.e. piling noise (SMRU 2007; Coram *et al.* 2014).

Sample sizes were too low to assess the responses of marine mammals to the soft start of piling. The fact that there were only three sightings of seals and none of cetaceans that first appeared during the soft start of impact piling is perhaps indicative of avoidance, although relatively little time was spent monitoring during the soft start. However, given the low monitoring effort the fact that any mammals were seen at all during the soft start suggests that not all animals may be deterred by the soft start, particularly in the case of the grey seal that appeared 17 minutes into the soft start. It would not be unexpected that the response of marine mammals to a piling soft start might be similar to the response to a soft start on geophysical surveys, where there has been some evidence of displacement or avoidance but not all animals move away (Stone 2015, 2023b; Stone *et al.* 2017).

4.5 Considerations for future revisions to the guidelines

Many studies have contributed to knowledge gained since the JNCC guidelines for piling were last revised in 2010. This body of knowledge, together with the results of the present study, particularly in relation to the practical aspects of implementing the current guidelines, is drawn upon to make recommendations for revisions to the guidelines.

During projects between 2010 and 2021, there was little attempt to reduce noise from piling. Use of a big bubble curtain is considered to reduce sound to levels where auditory injuries would be unlikely in most cases (Stöber & Thomsen 2019). Several studies have found that the range of effects on harbour porpoises has been reduced by the use of bubble curtains and/or casings (Brandt *et al.* 2016; Nehls *et al.* 2016; Dähne *et al.* 2017). Dähne *et al.* (2017) noted that bubble curtains effectively reduced temporary habitat loss and risk of hearing loss and Nehls *et al.* (2016) found that the area of potential disturbance of harbour porpoises by pile-driving activities was reduced by 90%. However, not all results have been so promising: Rose *et al.* (2019) found that in Germany even though noise levels reduced due to improved noise mitigation, there was no reduction in response by harbour porpoises, with effects still present up to 17km and lasting up to 48 hours after piling stopped. They postulated that this could be due to:

- a stereotypical escape distance
- the deterrent effect of ADDs (although this was thought not be the only reason)
- other construction related noise (although the response to piling was stronger than the response before piling, at least at close range)
- cumulative effect
- or different habitat characteristics.

Verfuss *et al.* (2016a) showed that noise reduction measures could help to reduce the risk of a population decline due to the cumulative impacts of wind farm construction. Harbour porpoise populations could benefit from relatively small levels of noise reduction, with the risk of a 1% population decline due to wind farm construction reduced by 34% as a minimum and potentially up to 96%. Merchant and Robinson (2020) considered it was feasible to deploy noise abatement technologies at all locations where offshore wind farms were proposed in UK waters. They noted that bubble curtains and casing-based systems are effective in water depths up to 45m, while encapsulated resonator systems are in principle unlimited by depth.

It is therefore recommended that future licences for OWF construction in the UK sector should give more consideration to noise abatement, particularly for larger diameter piles where predicted injury ranges may be large. Currently there is a section in the guidelines where developers are required to demonstrate that they are using Best Available Technique, but this section needs to be updated. There should be a greater emphasis in the guidelines on noise abatement, whether reduction at source or reduced spread of noise. The guidelines should require that operators / developers investigate all potential options and choose appropriate methods to reduce noise or provide justification if they are unable to provide any noise reduction.

It is recommended that any reduced mitigation zone agreed with regulators based on predicted injury is conservative and that noise measurements are conducted early in the project to verify the predictions. Ideally, a minimum 500m mitigation zone should remain in place until there is evidence from noise monitoring to support any reduction in the size of the zone.

Another area that requires further consideration is the use of ADDs. They can be effective at deterring harbour porpoises (Brandt *et al.* 2012a, 2012b, 2013; Dähne *et al.* 2017; Rose *et al.* 2019; Thompson *et al.* 2020; Graham *et al.* 2023), but mixed results have been found for seals (Harris *et al.* 2014; Mikkelsen *et al.* 2017; Gordon *et al.* 2019). The potential for impacts from piling over considerable ranges and the difficulty of detecting animals over these ranges has led to questions over the efficacy of existing mitigation measures based on monitoring with MMOs and PAM (SMRU 2007; Herschel *et al.* 2013; Coram *et al.* 2014). Monitoring has been perceived as expensive due to the use of independent vessels patrolling the area (SMRU 2007; Herschel *et al.* 2013; Coram *et al.* 2014), although in recent years monitoring has been conducted from installation vessels. It has been suggested that ADDs and tailored soft starts could become the primary and preferred best practice mitigation option for UK OWF developments, with the phasing out of the use of MMOs and PAM (Herschel *et al.* 2013). Of the devices available, several (including the Lofitech) have been considered suitable for mitigation (Herschel *et al.* 2013; Sparling *et al.* 2015). This approach has already been adopted for some projects (BOWL 2015; Seagreen 2020). However, Sparling *et al.* (2015) cautioned that there were uncertainties regarding the effectiveness of ADDs for species other than harbour porpoises and seals. Furthermore, Herschel *et al.* (2013) quoted a maximum effective range of just 250m for pinnipeds, making them ineffective where predicted injury ranges are in excess of this. For baleen whales, one study found that minke whales swam away from a Lofitech device at significantly increased speed (McGarry *et al.* 2017) but another found no response in humpback whales (Basran *et al.* 2020). Devices other than the Lofitech have similarly been shown sometimes to deter harbour porpoises (Johnston 2002; Kastelein *et al.* 2017b) but not humpback whales (Harcourt *et al.* 2014; Pirotta *et al.* 2016) or striped dolphins (Kastelein *et al.* 2006), while there were mixed results for bottlenose dolphins (Leeney *et al.* 2007; Dííaz Lóópez & Mariñño 2011) and only a mildly evasive response in common dolphins (Berrow *et al.* 2008).

Whilst ADDs may be beneficial in deterring some marine mammals, the results here and in other studies show that not all animals are deterred. The proposal to use ADDs in place of monitoring with MMOs and PAM relies on the assumption that all animals will flee during use of an ADD (i.e. not only do they leave an area but they leave immediately and swim directly away). This assumption may be misplaced, perhaps particularly for seals. Any animals not deterred would be at risk of injury were piling to commence without monitoring and a delay. The instance of a harbour seal appearing in the mitigation zone towards the end of a period of ADD activation just one minute before a soft start was due to commence illustrates the residual risk of this approach. Had there been no monitoring the soft start would have commenced with the seal close by, with a risk of injury. As it was, piling was delayed until the seal had left the mitigation zone for at least 20 minutes, in accordance with the current JNCC guidelines, thus reducing the risk of injury. It is recommended that ADDs are only used in combination with monitoring and that delays continue to be enacted for any undeterred animals detected in the mitigation zone.

One difficulty of using ADDs in place of monitoring would be in assessing the effectiveness of this approach. Without monitoring during construction, it would be impossible to know whether ADD use had effectively deterred marine mammals or whether some animals had remained close by, as in the case of the harbour seal noted above. The OWF project with the phased mitigation protocol aimed to assess the effectiveness of each mitigation method (ADD and soft start only versus JNCC guidelines) through data collection and a summary report. However, there was no MMO report and only partial data collection during construction. An experimental study prior to the construction phase showed a reduction in acoustic detections of harbour porpoises following playbacks of a Lofitech ADD (Thompson *et al.* 2020), but the lack of full monitoring and data throughout construction meant that it was not possible to assess whether ADDs had effectively deterred animals during construction, particularly other species such as seals. A further study of acoustic detections of harbour porpoises conducted during construction of another OWF (for which an MMO report and data were not submitted) found a marked directional movement of porpoises away from the sound source during ADD use (Graham *et al.* 2023). However, equivalent studies have not been undertaken for other species, so there is currently insufficient evidence to support a move to using ADDs instead of MMOs and PAM.

As well as questions about the effectiveness of ADDs for a range of species, there have been some concerns about their use. Coram *et al.* (2014), whilst considering the benefits of using ADDs in terms of increased risk reduction and cost-effectiveness, raised concerns about the potential for hearing damage in animals frequently exposed to ADD signals, about habitat exclusion and the potential for adverse consequences such as separation of mothers and calves. Brandt *et al.* (2013) noted that harbour porpoises seem to be startled when an ADD is activated at close range and also were concerned about the potential for panic reactions that could lead to separation of mother-calf pairs. There have been concerns about potential auditory impairment of harbour seals and harbour porpoises exposed to noise from ADDs used in aquaculture (Findlay *et al.* 2021, 2022; Todd *et al.* 2021). 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 although this was not assessed. 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.

In addition to the potential for auditory impairment, there have also been concerns about the level of disturbance caused by ADDs. Some studies have found that where there is a response to ADDs, this can be of a similar magnitude to the response to piling. Rose *et al.* (2019) found that within a distance of at least 1.5km the response of harbour porpoises to ADDs (including the Lofitech device) was as strong as the response to piling itself. Thompson *et al.* (2020) found that there was ≥ 50% chance of harbour porpoises responding to playback of a Lofitech device at distances up to 21.7km away in the three hours following playback; they noted that strong responses of porpoises to this ADD resulted in far-field disturbance beyond that required to mitigate injury. Dähne *et al.* (2017) also noted a strong reaction of harbour porpoises to a Lofitech device and raised concerns that it could surpass the reaction to piling noise itself (when operating with bubble curtains). Furthermore, Graham *et al.* (2019) found preliminary evidence that short-term responses of harbour porpoises to the cumulative impact of ADD and impact piling were greater than responses to piling alone.

Given these concerns, some authors have called for caution when using ADDs. Graham *et al.* (2019) suggested that management efforts to reduce exposure to piling noise should be carefully balanced against potential disturbance associated with mitigation. 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), although for many ADDs the source level cannot be varied. For the same reasons there should perhaps also be consideration as to whether initiation of an ADD should take place if there is a marine mammal in close proximity, or whether there should be a delay in activation if marine mammals are in the mitigation zone just as there would be for piling. 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). Thompson *et al.* (2020) also noted that the duration of ADD use should be sufficient to deter animals from the near-field but minimised to avoid unnecessary far-field behavioural disturbance. The duration of ADD deployment should be determined on a case-by-case basis depending on the predicted injury zone. The guidelines should also require that there is no gap between the end of ADD activation and commencement of the piling soft start, to avoid the potential for animals returning. If a marine mammal approaches during ADD use and remains undeterred within the mitigation zone, the guidelines should recommend that the ADD is deactivated.

In spite of these concerns, there is a place for ADDs as part of a suite of mitigation measures in some cases, particularly if the injury zone extends beyond the range of detection by MMOs. Given the total absence of acoustic detections, using ADDs to deter marine mammals may be the more appropriate mitigation at night or as a supplement to visual observations in poor conditions. However, as ADDs do not deter all animals, avoiding starting at night or in poor conditions would be the better approach. Mitigation for seals at night is particularly difficult as they are not detected with PAM and not always deterred by ADDs. It is recognised that there are cost implications of only commencing piling during daylight, but with appropriate planning it could be viable for shorter duration projects. Where projects are of longer duration, as well as the cost implications of not being able to start at night, any additional impact on marine mammals due to the potential increase in overall duration of a project would need to be considered. Given that displacement may persist for several hours following piling (Carstensen *et al.* 2006; Tougaard *et al.* 2006b, 2013b; Thompson *et al.* 2010; Brandt *et al.* 2011, 2016, 2018; Geelhoed *et al.* 2018), one solution might be to allow piling to commence at night or in poor conditions (with ADDs and a soft start, and monitoring by MMOs in daylight) if there had only been a few hours since piling last stopped, but if there had been a longer gap then piling should not commence until effective visual monitoring could be undertaken. If not commencing at night or in poor conditions is considered unfeasible then noise abatement to reduce the predicted injury zone should be mandatory (alongside the use of a soft start, and monitoring by MMOs in daylight).

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.

If PAM does continue to be used, the guidelines should clarify that it should not be used as a substitute for visual monitoring except during hours of darkness or in restricted visibility such that the full extent of the mitigation zone cannot be seen. Analysis of MMO and PAM data from geophysical surveys found that visual detection rates were similar or significantly greater than acoustic detection rates for all species or species groups tested, including in suboptimal sea conditions (Stone 2023a). In increased sea conditions, both visual monitoring and PAM (where available) should be used if there are enough personnel to use both concurrently, but if there has to be a choice between methods then visual monitoring should be used. Although this advice has been introduced in JNCC's PAM guidance (JNCC 2023), it should also be incorporated into the piling guidelines.

It is important that sufficient numbers of MMOs and PAM operators are engaged. The guidelines should state that having a single person performing both the MMO and PAM operator role is not acceptable. The guidelines should recommend that the mitigation team should be on the installation vessel to ensure that they are always available for a pre-piling search. There should be consideration regarding whether two MMOs would need to observe together to cover the whole mitigation zone, depending on the layout of the installation vessel, and if that is the case the number of personnel should allow for that whilst still allowing for sufficient breaks for each person.

A recent study has shown a strong directional movement of harbour porpoises away from the sound source during a soft start of piling, with evasive responses recorded up to 9km away (Graham *et al.* 2023). Although evidence for other species is lacking, this study suggests that the soft start may be an effective measure to reduce the risk of injury when piling commences, particularly for animals that may have escaped detection. The guidelines describe a soft start as "the gradual ramping up of piling power, incrementally over a set time period, until full operational power is achieved". There could perhaps be more guidance on how a soft start could best be achieved. Thompson *et al.* (2020) suggested that soft starts could be improved by having an extended initial phase of piling at low blow rates and also further reducing the hammer energy during these initial strikes. This may be particularly important for projects in waters of sufficient depth that most or all of the pile is in the water column during the initial stages of piling and a higher proportion of hammer energy is converted into waterborne acoustic energy (Thompson *et al.* 2020). Herschel *et al.* (2013) recommended that the duration of a soft start should be tailored to ensure that all animals can swim at least twice the distance of the injury zone during the soft start time but noted that much longer starts would yield negligible gains.

As ADDs may not effectively deter all animals and the response of marine mammals to the soft start is unknown for many species, there is a continuing need to delay for any marine mammal detected in the mitigation zone. There should be clarification of the procedures to follow if a delay is required due to a marine mammal in the mitigation zone prior to the soft start. The wording should be amended to make it clear that the delay should last until 20 minutes after the last detection in the mitigation zone. It is suggested that similar wording is used as in the geophysical survey guidelines (JNCC 2017): "There must be a minimum of a 20-minute delay from the time of the last detection within the mitigation zone until the commencement of the soft-start, to allow animals unavailable for detection (i.e. not re-surfacing in that time) to have moved outside of the mitigation zone."

The guidelines also require mitigation action if a marine mammal is detected in the mitigation zone during the soft start. This necessitates monitoring throughout the soft start, but the guidelines currently only require monitoring prior to piling. The guidelines should require that monitoring continues after the pre-piling search throughout the soft start. Although some reports commented on the difficulty of stopping once piling was underway, on both occasions when a marine mammal entered the mitigation zone during the soft start, piling was stopped. The guidelines already provide the alternative of no further increases in energy, about which no comments were received. It is therefore recommended that the requirement to stop piling, or not increase the energy any further, if a marine mammal is detected in the mitigation zone during the soft start remains.

The JNCC guidelines require that there is another soft start if there is a break in piling of more than 10 minutes. Similarly, where ADDs were used on some OWF projects, the protocols included reactivating ADDs if there was a break in piling of more than 10 minutes (although this was increased to one hour for the latter part of one project). The requirement to repeat the soft start was mostly not complied with; a number of reports commented on the difficulty of performing another soft start on a partially driven pile. Given the difficulties of performing a soft start in such situations, utilising ADDs to deter at least some animals could be an appropriate alternative. However, there should be consideration of the duration of a break after which an ADD and/or a soft start would be required. Kastelein *et al.* (2015a, 2015b) considered that it was necessary to determine the timeframe within which marine mammal behaviour returns to normal after piling ceases in order to inform the decision to use ADDs. Thompson *et al.* (2020) considered that 10 minutes may be too short and recommended only requiring ADDs after a longer break in piling, which they considered would also reduce broader-scale disturbance. Some studies have found that effects of piling persist for at least a few hours (Tougaard *et al.* 2006b, 2013b; Brandt *et al.* 2018; Geelhoed *et al.* 2018), while in the present study the minimum wait time until the next marine mammal detection after impact piling ceased was 45 minutes. It is therefore suggested that the duration of a break after which a soft start would be required (or an ADD if a soft start was not technically possible) could be extended to 45 minutes for impact piling, although monitoring should be continued during the break and resumption of piling delayed if a marine mammal is detected in the mitigation zone. If the break is less than 45 minutes and monitoring confirms that no marine mammals are in the mitigation zone, then piling could resume at the energy level it was at before the break. Although soft starts are not always possible with vibratory piling or pile drilling, if ADDs are used following a break in these methods of piling, it is suggested that the 10 minute threshold is retained, as the minimum wait time was less for these types of piling than it was for impact piling.

Although the guidelines recommend another pre-piling search and soft start for breaks of more than 10 minutes, there is no guidance about what to do for shorter breaks. One MMO report recommended that there was clarification of requirements in such situations. The geophysical survey guidelines recommend that a check is made of the mitigation zone to ensure no marine mammals are present before data collection resumes, but this is not specified in the piling guidelines. There were not many recorded short breaks during piling, but in all cases monitoring that was already ongoing continued. No cetaceans were first seen while piling was underway and studies suggest that the deterrent effect of piling on cetaceans persist for at least a few hours after piling ceases (Carstensen *et al.* 2006; Tougaard *et al.* 2006b, 2013b; Thompson *et al.* 2010; Brandt *et al.* 2011, 2016, 2018; Geelhoed *et al.* 2018). This might suggest that a search of the mitigation zone during a short break in piling is unnecessary. However, despite lower detection rates when piling, seals did appear while piling was underway on several occasions. Therefore, a check for animals in the mitigation zone before piling resumes after a short break, and a delay (followed by a soft start) if any are detected, would be recommended. This should also apply if the time allowed before another soft start is required is extended.

Given the number of MMO reports and data that 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 Marine Mammal Mitigation Plans 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 piling, there are some columns that are not relevant and other information that would be relevant is omitted. Separate forms should be designed for piling; a list of recommended items to be included on the forms is listed in Appendix 2.

Of particular importance is the facility to record the times that ADDs were active on the Operations form. Correspondingly, source activity on the Effort form and the record of piling activity when animals are first and last detected on the Sighting form should include ADD as an option. Details of ADDs (type, number and frequency) should be included on the Cover Page.

Information specific to geophysical surveys on the Cover Page should be replaced with information relevant to piling, e.g. type of piling, hammer energy, pile diameter and blow rate. Space to include the number of non-dedicated MMOs as well as dedicated MMOs is recommended.

The Operations form should have the facility to record the particulars of each period of piling activity. Although bubble curtains were not used for any of the projects examined, the facility to record their use should be included for future projects. The hammer used on each occasion should be recorded (as more than one hammer may be specified on the Cover Page) and the maximum energy reached. MMO reports show that this information is readily available to MMOs. The source (i.e. type of piling, whether impact or vibratory etc.) should be recorded for each period of piling as some projects may use more than one method and although both would be listed on the Cover Page, there is a need to distinguish which method was used when.

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 piling operations. 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 using MMO / PAM data from UK O&G and OWF projects to examine the response of marine mammals to piling and compliance with the JNCC piling guidelines. It was limited by the lack of available data, particularly for OWF projects. Nevertheless, some conclusions can be drawn.

Compliance with JNCC guidelines was generally good but there was room for improvement in some areas. Pre-piling searches could be improved by not substituting a visual search with PAM in conditions where a visual search is still effective; PAM should be complementary to the visual search rather than instead of it. Soft starts were often absent after a break in piling due to operational difficulties. There were differing interpretations of the duration of delays required due to marine mammals in the mitigation zone.

One third of piling events started at night. There was a different approach to mitigation at night between the different industries, with O&G projects mostly using PAM while OWF projects sometimes used PAM but more often relied on ADDs. Neither provided an ideal mitigation solution, as there were no acoustic detections and ADDs were not completely effective, particularly for seals. Mitigation at night, particularly for seals, is challenging.

Generally, piling projects did not employ the full suite of mitigation measures available. MMOs were used on all projects reported here (with the exception of part of one project) but there is a move away from using MMOs on OWF projects. PAM was widely used on O&G projects but less so on OWF projects, although where it was used on OWF projects it tended to be used by day as well as at night, albeit sometimes at the expense of visual monitoring. There was a move towards the use of ADDs on OWF projects, with ADDs being used prior to half of the piling events during OWF construction, but they were not used on O&G projects. Soft starts were used on all projects involving impact piling but could not be used for vibratory piling or pile drilling. Noise abatement, whilst practised during piling in other sectors of the North Sea, did not regularly feature in UK projects.

No single method of mitigation is 100% effective. MMOs may miss animals and cannot observe over the full range where impacts may potentially occur, although mitigation with MMOs may be effective where predicted injury zones are small. There were no acoustic detections during the projects reported here; while PAM may be useful particularly for harbour porpoises at close range, it is not suitable for seals (which were encountered more often than cetaceans during piling projects) or minke whales. ADDs may effectively deter harbour porpoises but are less effective for seals and there is limited evidence for other species; furthermore, there should be caution regarding the additional noise introduced. Although using a soft start to commence piling at lower energy levels should reduce the risk of injury to marine mammals, whether animals move away during the progression of the soft start is unknown for most species. It is recommended that the full suite of mitigation measures is used in future piling projects, with monitoring alongside the use of soft starts and (where appropriate) ADDs, and more use of noise abatement to reduce predicted injury zones.

In the light of the results of this analysis, some recommendations for changes to the JNCC guidelines for piling are made. These include: a greater emphasis on noise abatement; a conservative approach when variations from the guidelines are allowed; continued monitoring alongside the use of ADDs; caution in the use of ADDs to reduce the risk of TTS and far-field disturbance; restrictions on starting at night or in poor monitoring conditions; clarifying that PAM should not be used as a substitute for visual monitoring except during hours of darkness or in restricted visibility such that the full extent of the mitigation zone cannot be seen; providing sufficient numbers of MMOs and PAM operators; recommending that mitigation personnel are on the installation vessel; clarification of the correct timings when a delay is required; consideration of how best to achieve a soft start; revision of procedures following a break in piling; 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 piling operations are also made.

Although sample sizes were low, analysis of the data indicated displacement of cetaceans and seals by impact piling, in line with other studies. No longer term effects were apparent, but caution should be applied due to the limited data. There were indications that seals were disturbed to some extent during pile drilling, with fewer seals hauled out, but again sample sizes were low. There were insufficient data to examine responses to vibratory piling or to analyse responses to the soft start or ADDs, although there were behavioural observations of several sightings during ADD use that suggested effectiveness was limited for seals. Collation of MMO data should continue to enable further analysis in future.

The current project focussed on piling in the O&G and OWF industries and all but one of the projects examined were offshore. Responses in the inshore environment may differ; analysis of data for coastal construction projects could shed more light on responses in the inshore environment and potentially enable analysis of responses to vibratory piling as well as impact piling.

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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).

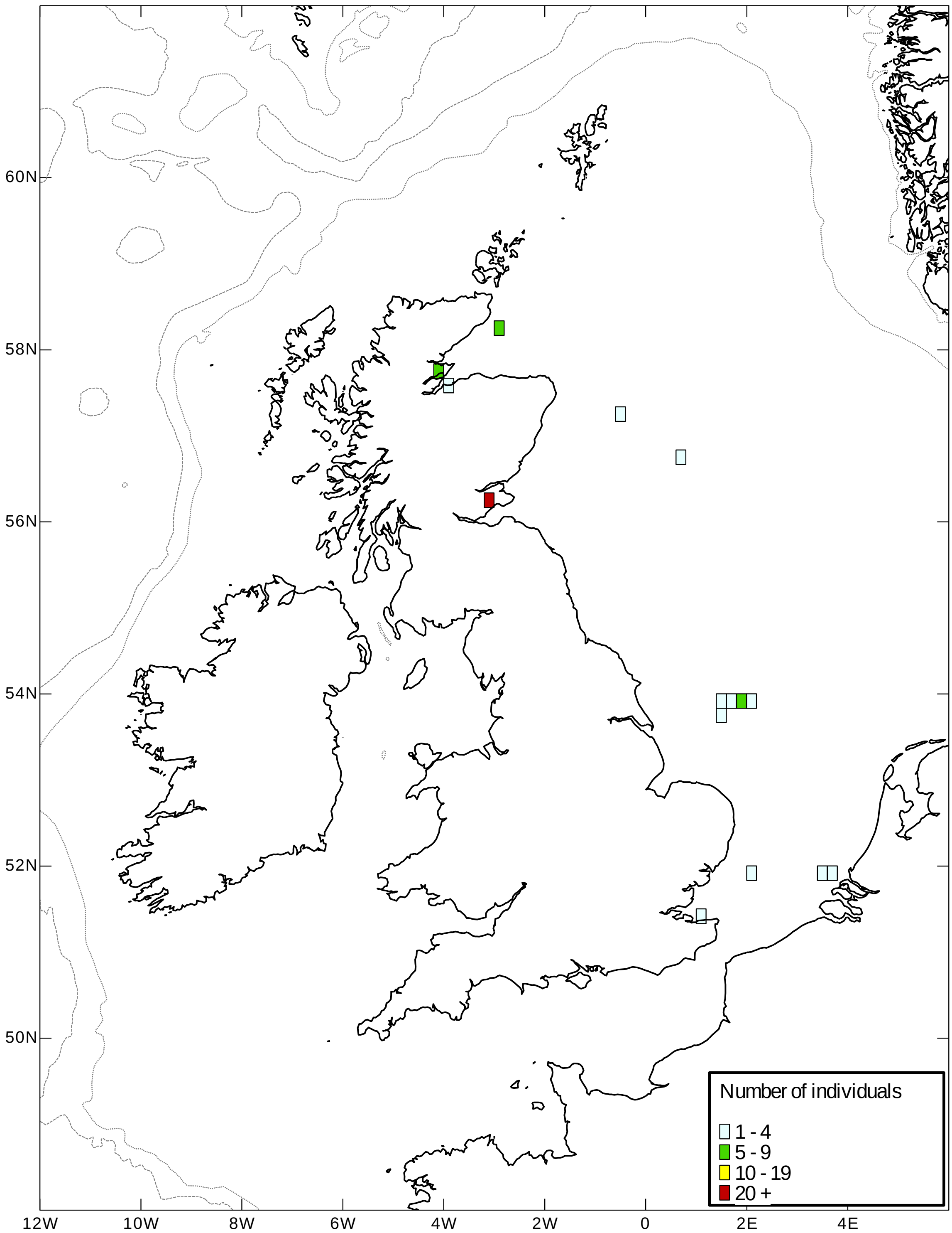

Figure 14. Grey seals encountered during piling projects, 2011-2021.

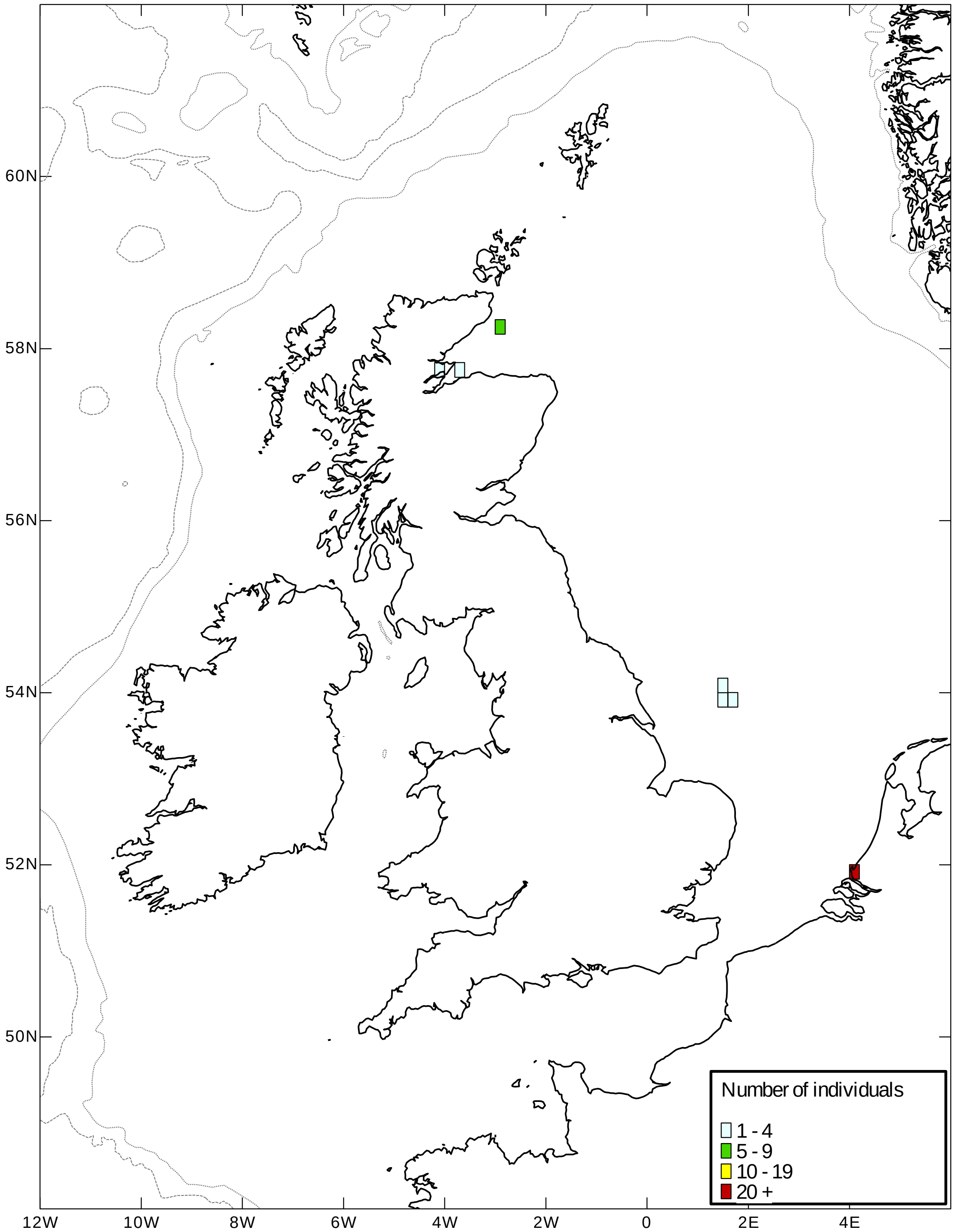

Figure 15. Harbour seals encountered during piling projects, 2011-2021.

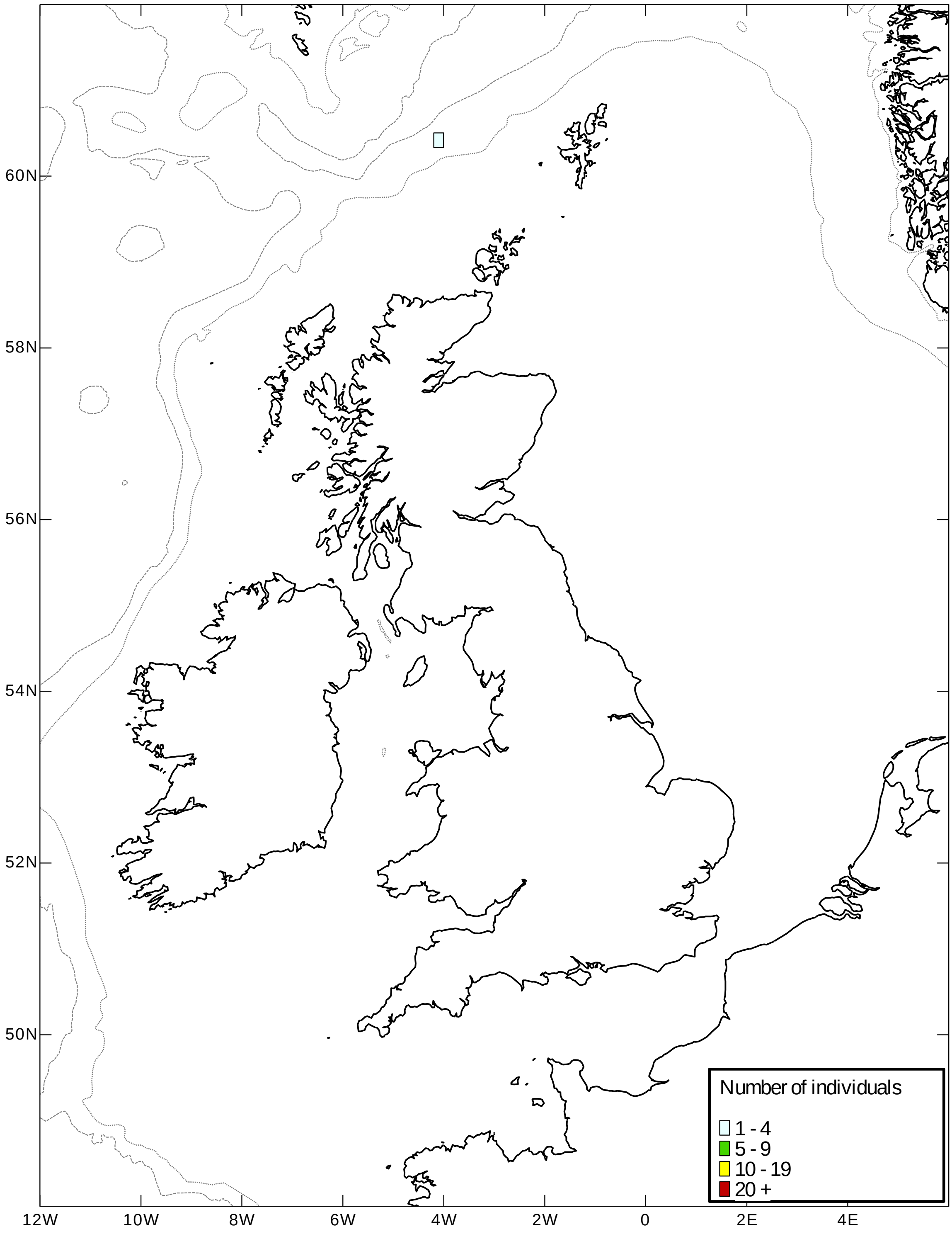

Figure 16. Fin whales encountered during piling projects, 2011-2021.

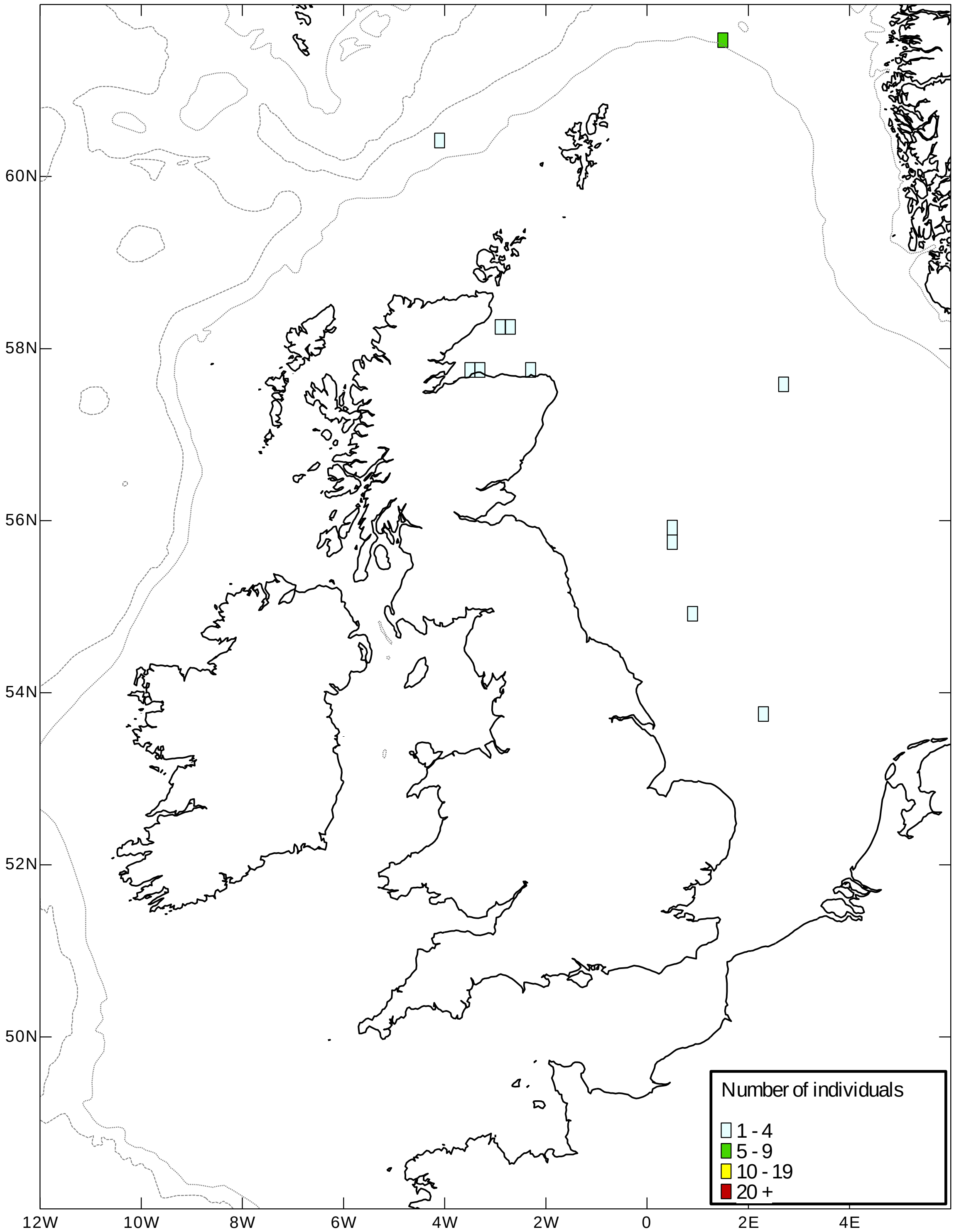

Figure 17. Minke whales encountered during piling projects, 2011-2021.

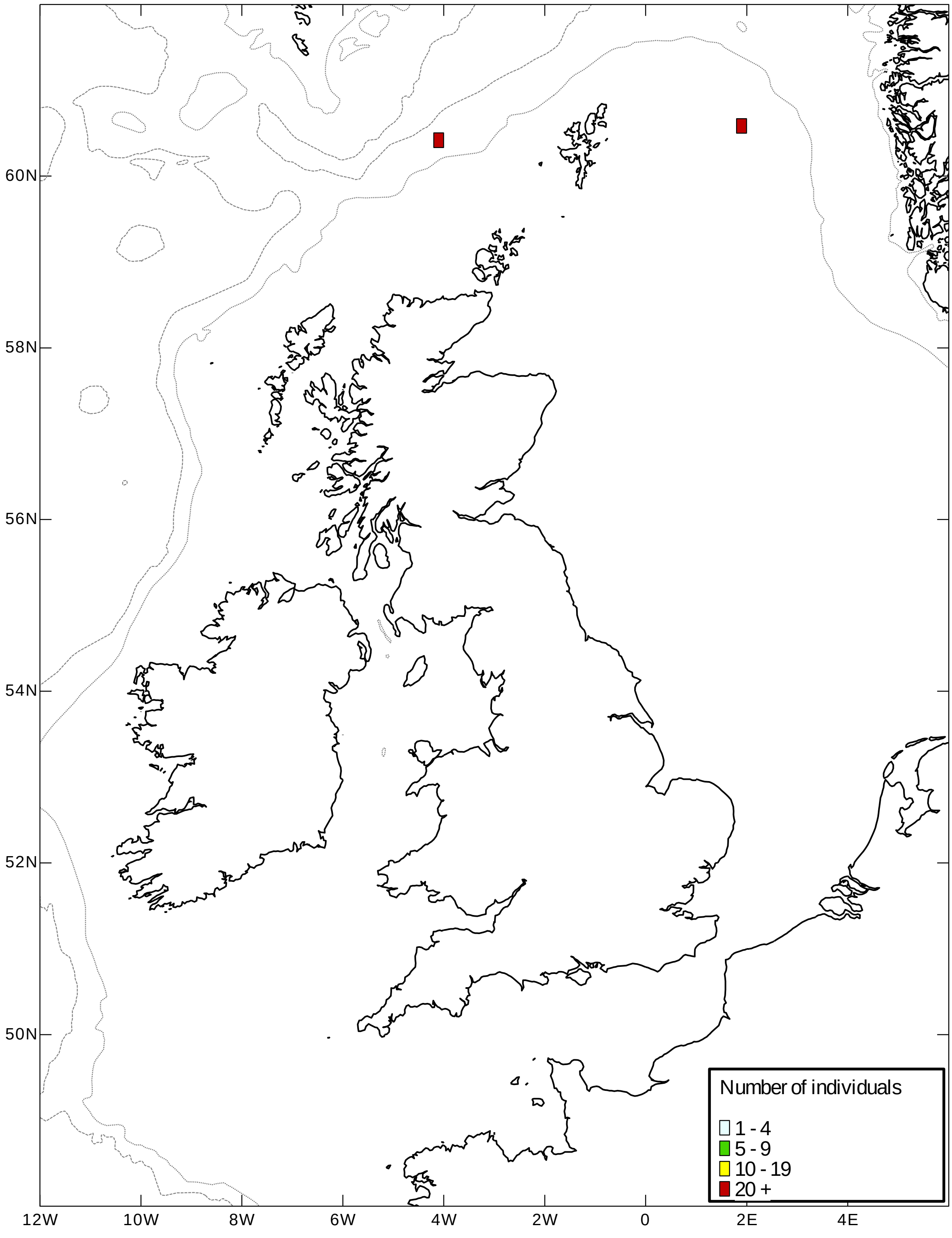

Figure 18. Long-finned pilot whales encountered during piling projects, 2011-2021.

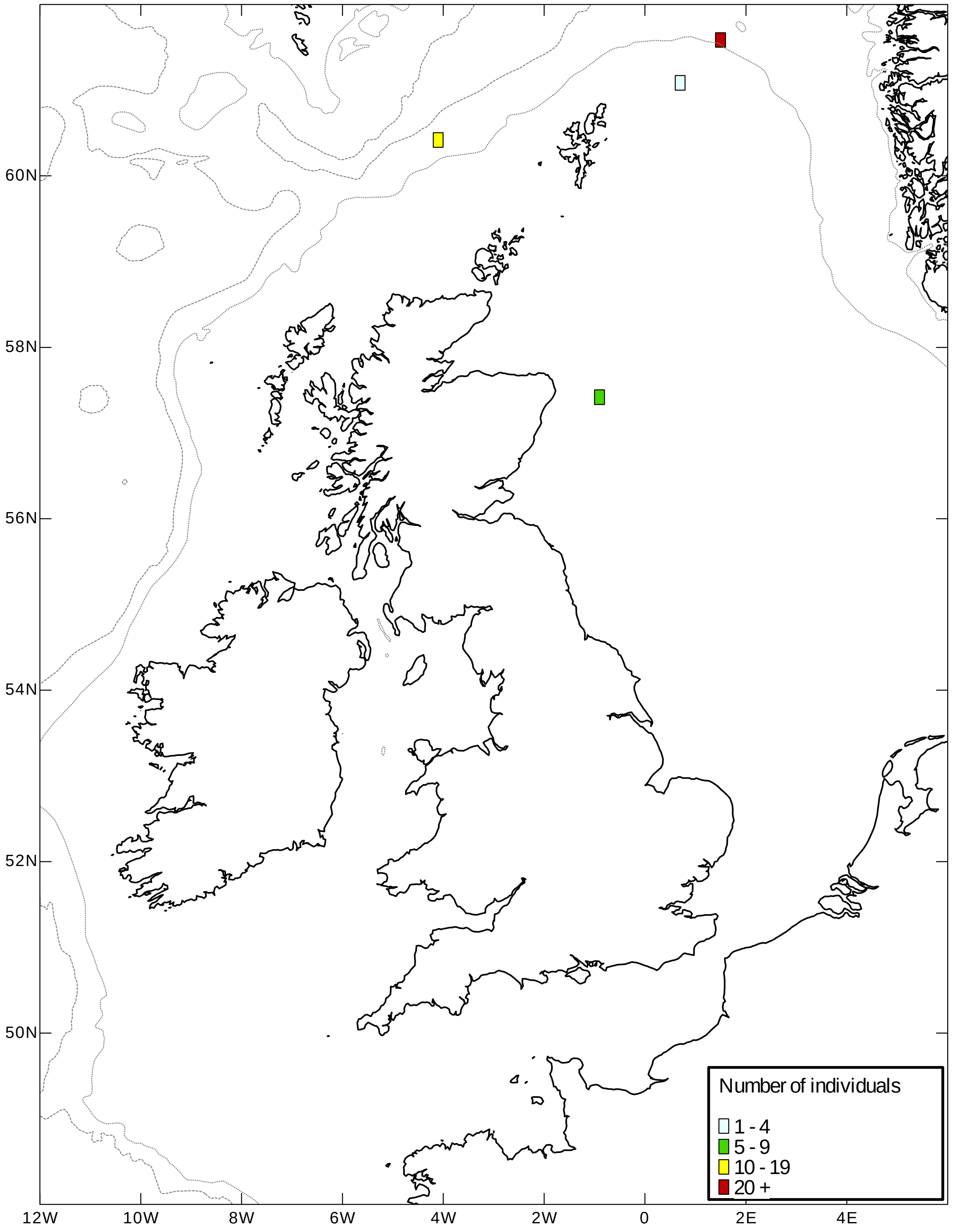

Figure 19. Killer whales encountered during piling projects, 2011-2021.

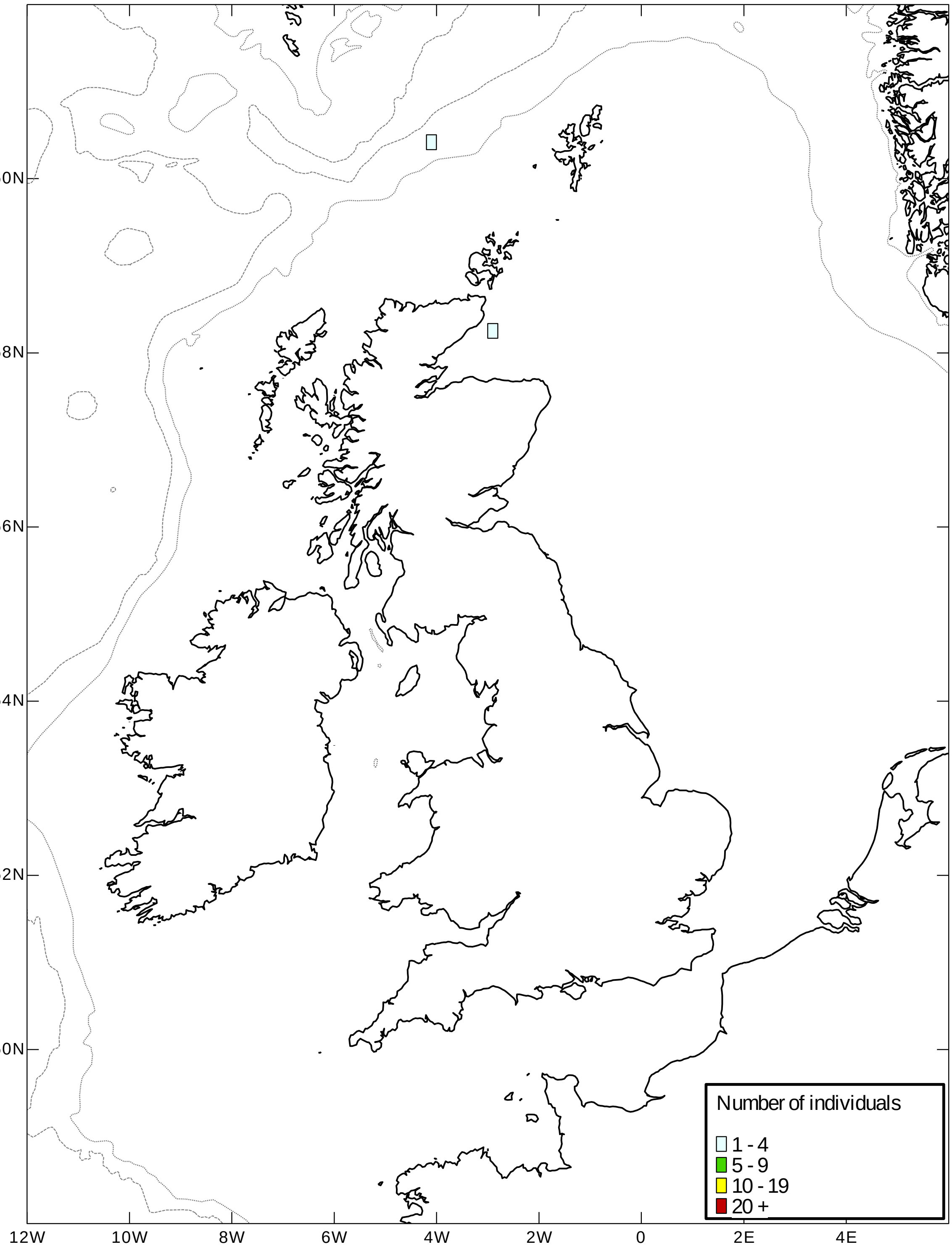

Figure 20. Risso's dolphins encountered during piling projects, 2011-2021.

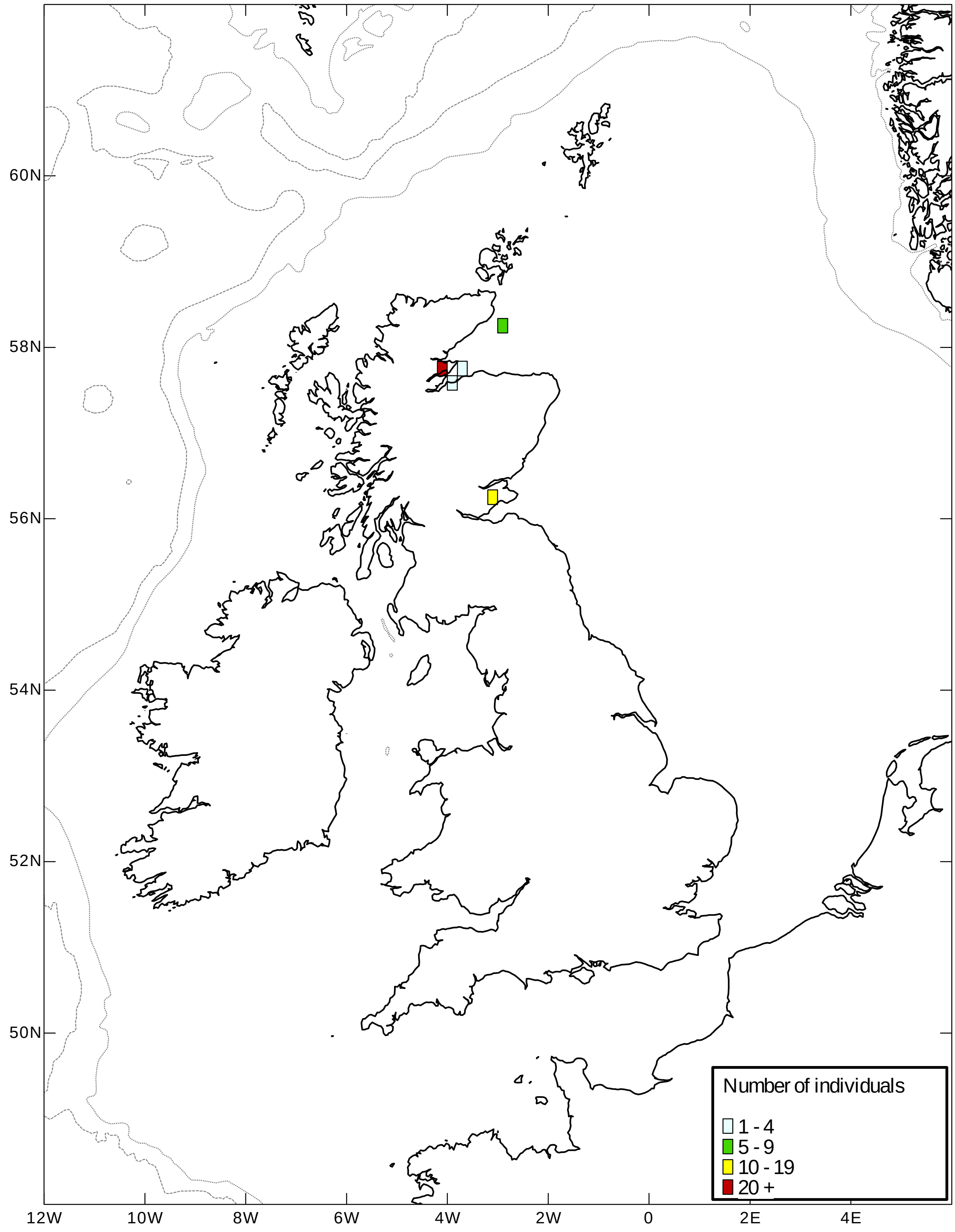

Figure 21. Bottlenose dolphins encountered during piling projects, 2011-2021.

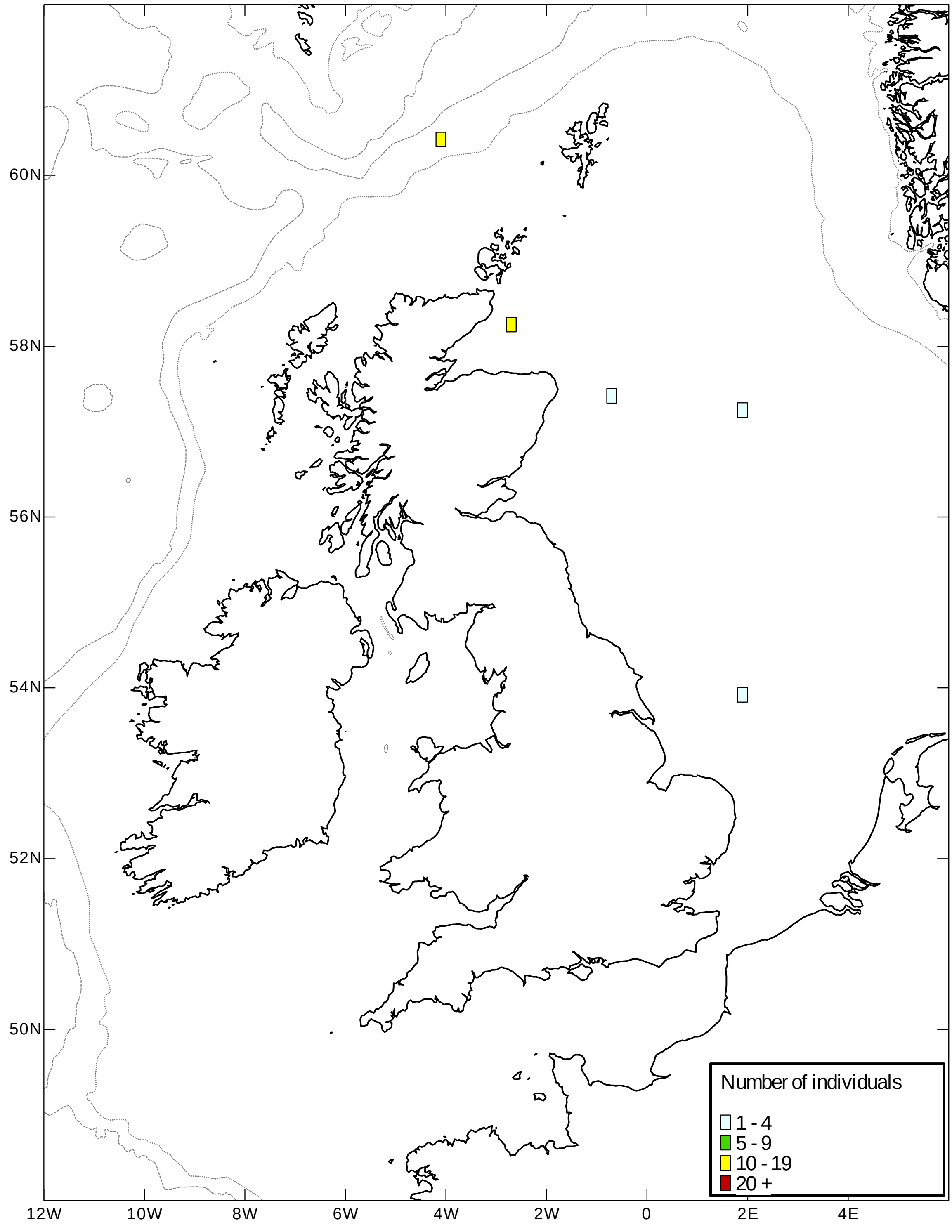

Figure 22. White-beaked dolphins encountered during piling projects, 2011-2021.

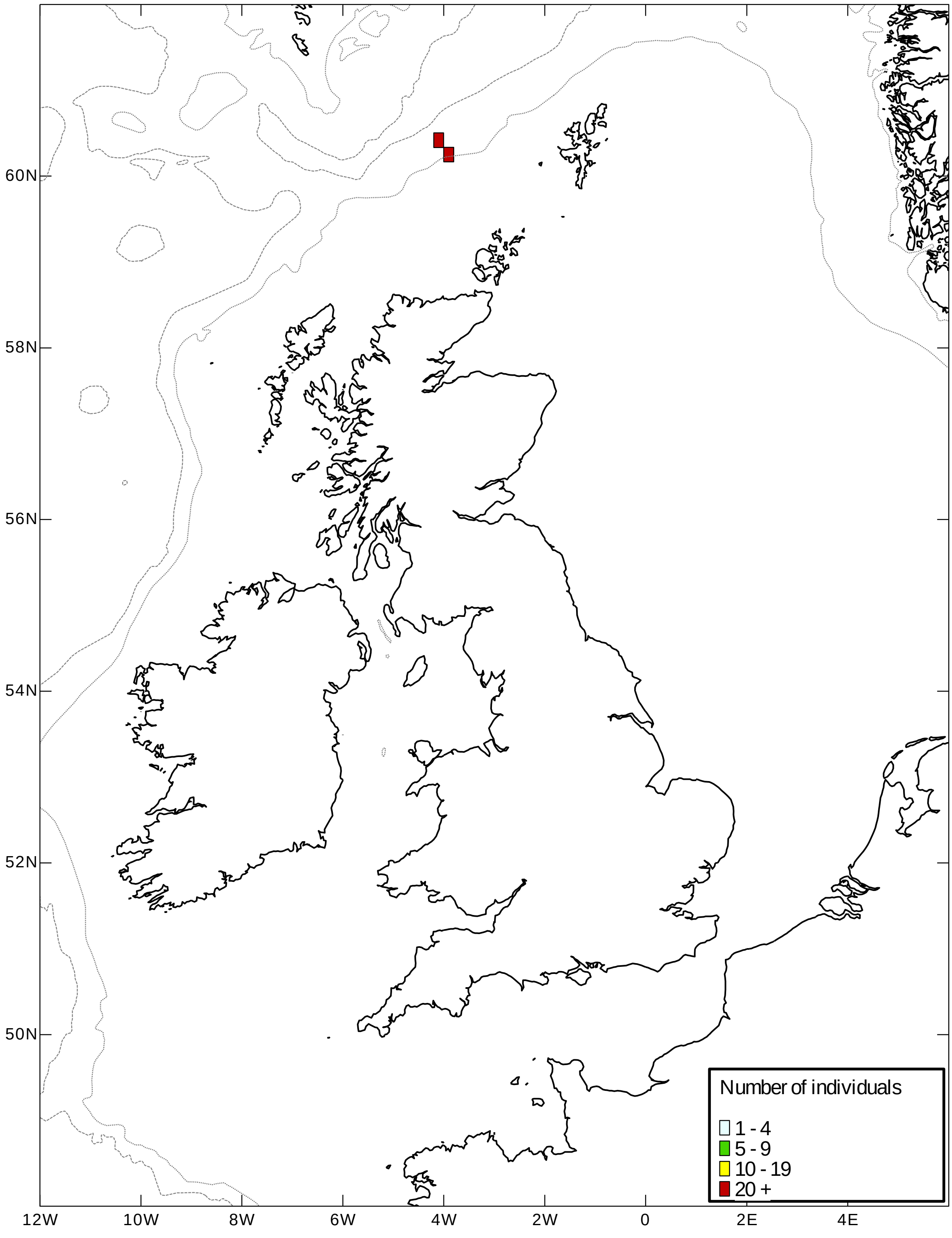

Figure 23. Atlantic white-sided dolphins encountered during piling projects, 2011-2021.

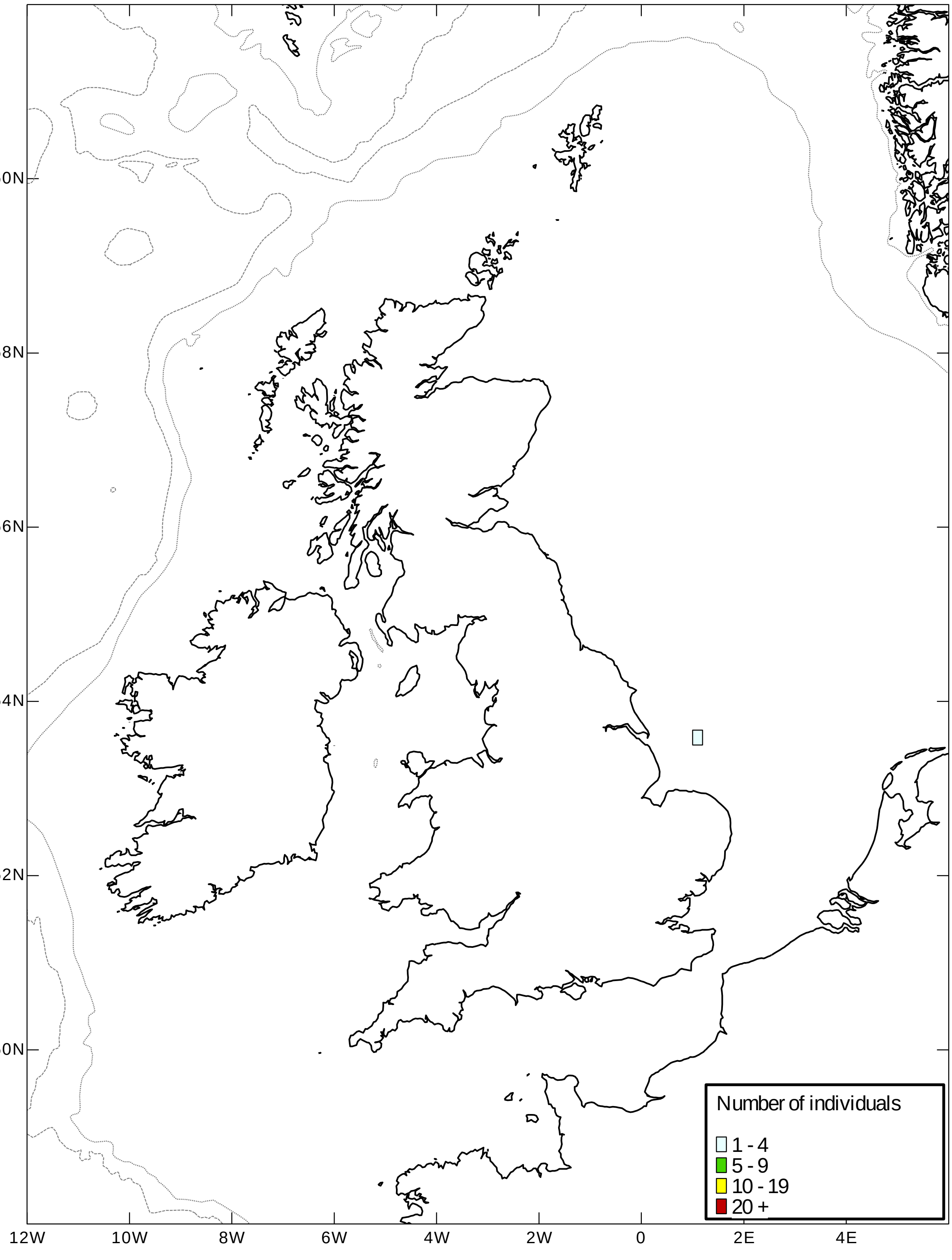

Figure 24. Common dolphins encountered during piling projects, 2011-2021.

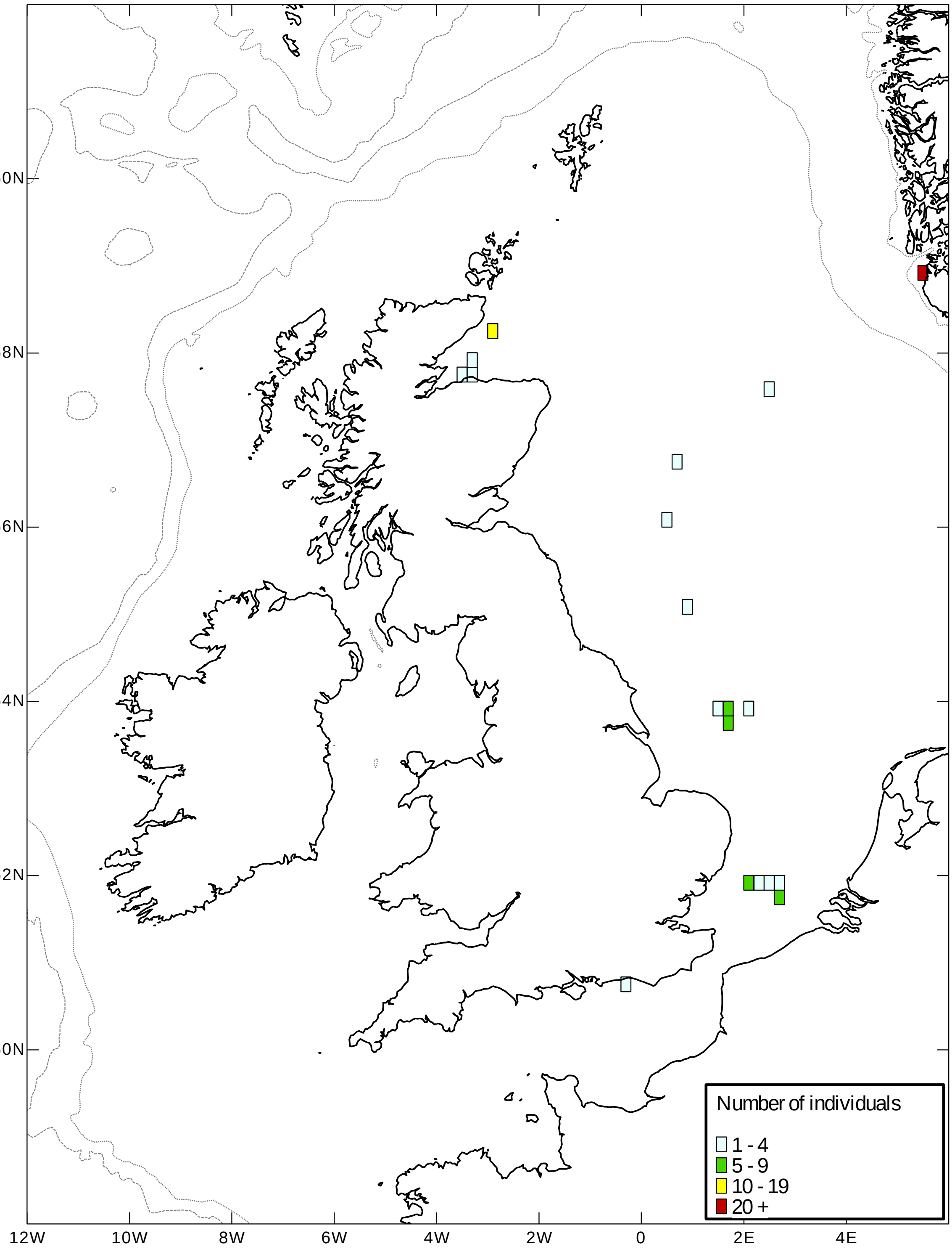

Figure 25. Harbour porpoises encountered during piling projects, 2011-2021.

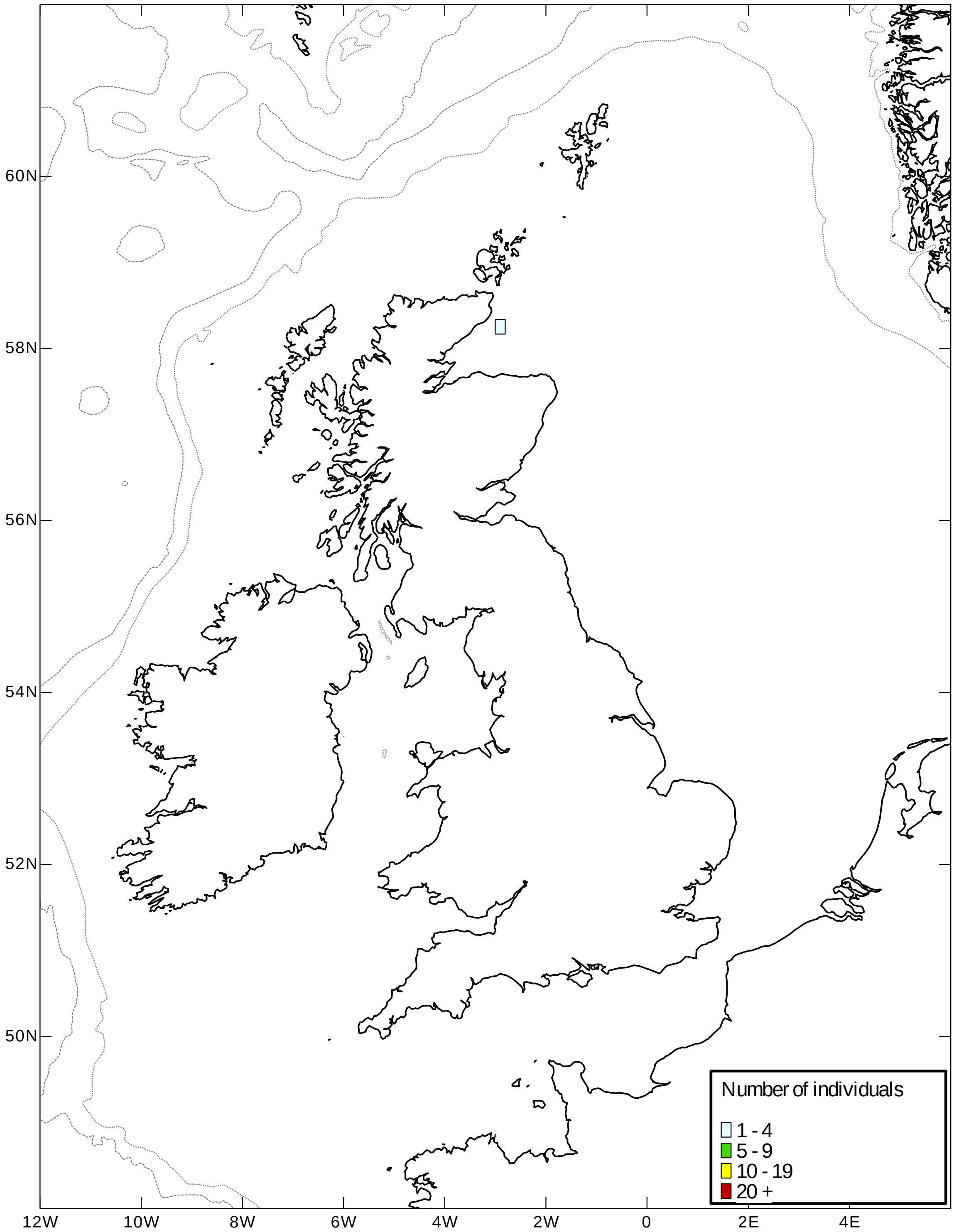

Figure 26. Basking sharks encountered during piling projects, 2011-2021.

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

Cover Page:

- Regulatory reference number
- Country
- Location
- Quad
- Ship / platform name
- Client
- Contractor
- Industry (OG, OWF, coastal construction, etc.)
- Start date
- End date
- Type of piling (impact, vibratory, pile drilling, etc.)
- Hammer energy (kJ)
- Pile diameter (metres)
- Piling depth (metres)
- Frequency (Hz)
- Intensity (dB re. 1µPa or bar metres)
- Blow rate (blows per minute)
- Method of soft start (increase energy, increase bpm, increase energy + bpm, etc.)
- Visual monitoring equipment used
- Magnification of optical equipment
- Height of eye (metres)
- How was distance of animals estimated?
- Number of dedicated MMOs
- Number of non-dedicated MMOs
- Training of MMOs
- Was PAM used?
- Number of PAM operators (PAM only)
- Description of PAM equipment (PAM only)
- Range of hydrophones from airguns (PAM only)
- Bearing of hydrophones from airguns (PAM only)
- Depth of hydrophones (PAM only)
- ADD used
- 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 soft start began (UTC)
- Time of full power (UTC)

- Time of reduced energy (if relevant) (UTC)
- Time piling stopped (UTC)
- Time pre-piling search began (UTC)
- Time search ended (UTC)
- Time PAM began (UTC)
- Time PAM ended (UTC)
- Depth
- Was it day or night in the period prior to piling?
- Was any mitigating action required?
- Hammer used (kJ)
- Maximum energy used (kJ)
- Source (impact piling, vibratory piling, pile drilling, etc.)
- 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 piling, ADD, soft start, full power, reduced power)
- 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)
- Piling activity when animals first detected (not piling, ADD, soft start, full power, reduced power)
- Piling activity when animals last detected (not piling, ADD, soft start, full power, reduced power)
- Time animals entered the mitigation zone (if relevant) (UTC)
- Time animals left the mitigation zone (if relevant) (UTC)
- Closest distance of animals from pile (metres)
- Time of closest approach (UTC)
- First observed distance during soft start (if relevant) (metres)
- Closest observed distance during soft start (if relevant) (metres)
- Last observed distance during soft start (if relevant) (metres)
- What action was taken?
- Length of power-down and/or shut-down (if relevant)
- 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*
Blue whale	*Balaenoptera musculus*
Fin whale	*Balaenoptera physalus*
Sei whale	*Balaenoptera borealis*
Minke whale	*Balaenoptera acutorostrata*
Long-finned pilot whale	*Globicephala melas*
Killer whale	*Orcinus orca*
False killer whale	*Pseudorca crassidens*
Risso's dolphin	*Grampus griseus*
Bottlenose dolphin	*Tursiops truncatus*
White-beaked dolphin	*Lagenorhynchus albirostris*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Common dolphin	*Delphinus delphis*
Striped dolphin	*Stenella coeruleoalba*
Harbour porpoise	*Phocoena phocoena*
Basking shark	*Cetorhinus maximus*

Appendix 4 - Glossary

Acoustic deterrent device (ADD): A device that emits an acoustic output which, although differing between devices, is intended to deter animals from a specific hazard / area.

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

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 equipment (e.g. impact hammer) at its full operational level, reached at the end of a soft start.

Impact piling: A method of driving a pile into substrate utilising a heavy ram weight that is raised mechanically or hydraulically to some height and dropped onto the head of the pile. Impact piling produces a very high-level impulsive noise that can be detected many kilometres away from the construction site. The level of sound generated depends on parameters such as the type of the pile, the amount of energy output from the hammer and the environmental properties of the site such as the seafloor sediment and area bathymetry.

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

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

Mitigation zone: The area where an MMO or PAM operator keeps watch for marine mammals (and delays the start of activity should any marine mammals be detected); currently recommended as a radius of no less than 500 m from the pile location.

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

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

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

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 for 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.

Pile drilling: Drilled piles are installed using drill bits to simultaneously install casing as the pile bore is advanced. Sometimes rotary percussive hammers are used together with the drill bit, supplying impact energy to aid the drilling.

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

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

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

Source: The source of the noise (e.g. piling).

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.

Vibratory (or vibro) piling: A method in which the pile is vibrated into the sediment rather than being hammered in. An oscillating driver is clamped to the top of the pile and creates vibrations in the pile that reduce friction along its sides, lessening resistance and allowing the pile to be inserted into the substrate aided by the weight of the driver. The sound generated from vibratory pile driving is more non-impulsive, continuous sound as opposed to the impulsive sounds produced from impact pile driving.