# Annex 2

# ‘Measures and Techniques to Mitigate the Impact of Seismic Surveys’ of the OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise

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# Measures and Techniques to Mitigate the Impact of Seismic Surveys

## Contents

## Acronyms

| Abbreviation | Definition |
|---|---|
| ASV | Autonomous Surface Vehicle |
| AUV | Autonomous Underwater Vehicle |
| CCS | Carbon Capture and Storage |
| dB | deciBel |
| EIA | Environmental Impact Assessment |
| FLO | Fisheries Liaison Officer |
| GES | Good Environmental Status |
| HRG | High-Resolution Geophysical |
| IMR | Institute for Marine Research (Norway) |
| IOGP | International Association of Oil and Gas Producers |
| JNCC | Joint Nature Conservation Committee |
| LoFS | Life of Field Seismic |
| MBES | Multibeam Echosounder |
| MCZ | Marine Conservation Zone |
| MMO | Marine Mammal Observer |
| MNR | Marine Noise Registry |
| MPA | Marine Protected Area |
| MSFD | Marine Strategy Framework Directive |
| NCMPA | Nature Conservation Marine Protected Area |
| NCS | Norwegian Continental Shelf |
| OBN | Ocean Bottom Node |
| PAM | Passive Acoustic Monitoring |
| PCAD | Population Consequences of Acoustic Disturbance |
| PCoD | Population Consequences of Disturbance |
| PRM | Permanent Reservoir Monitoring |
| PSO | Protected Species Observer |
| PTS | Permanent Threshold Shift |
| ROV | Remotely Operated Vehicle |
| RPAM | Remote Passive Acoustic Monitoring |
| SAC | Special Area of Conservation |
| SBP | Sub Bottom Profiler |
| SEL | Sound Exposure Level |
| SML JIP | Sound and Marine Life Joint Industry Programme |
| SPL | Sound Pressure Level |
| TTS | Temporary Threshold Shift |
| USV | Unmanned Surface Vehicle |
| VSP | Vertical Seismic Profile |

## 1. Introduction

Concern regarding the potential for underwater sound from geophysical surveys to impact marine species, especially cetaceans, led to the development of guidance by the United Kingdom's Joint Nature Conservation Committee (JNCC) in 1995. That guidance has been variously adopted and adapted globally within other jurisdictions where marine geoscience surveys are conducted. Key elements of the varying guidance implemented globally are a range of largely common mitigation procedures, tools and technologies focused on detecting the presence of protected marine species (principally cetaceans, but including large pelagic fish species, marine reptiles and seabirds) and then enacting delays, sound source reductions, or stoppages in order to limit the exposure of those species to high sound levels. Guidance such as that issued by the JNCC is applied in some parts of the OSPAR region and represents one element of the overall licensing and regulatory process for seismic surveys.

## 2. Comparison of Worldwide Guidelines

A number of reviews of worldwide mitigation guidance have been undertaken previously (see; Castellote, 2007; Compton et al., 2008; Weir & Dolman, 2007). Included here is a non-exhaustive list for comparison where such have been developed and remain relevant to marine geoscience activities for a range of applications including exploration, carbon storage and other requirements.

*Table 1 comparison of mitigation guidelines within and beyond the OSPAR region*

# Annex 2

| Guideline element | United Kingdom | United States of America | Australia | Brazil | Canada | Denmark | Greenland | Ireland | Israel | Mediterranean & Black Seas | Netherlands | New Zealand | Spain | Industry Best Practice |
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| **Regulatory agency / administering organisation** | Joint Nature Conservation Committee | Bureau of Ocean Energy Management | Environment Australia | IBAMA | Department of Fisheries & Oceans | Danish Energy Agency | Mineral Resources Authority of Greenland | National Parks and Wildlife Service | Ministry of the Environment | ACCOBAMS | Rijkswaterstaat | Department of Conservation | Ministry for the Ecological Transition and the Demographic Challenge | IOGP / EnerGeo Alliance |
| **Document title** | JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys.[1] | Biological Opinion on the Federally Regulated Oil and Gas Program Activities in the Gulf of Mexico.[2] | EPBC Act Policy Statement 2.1 – Interaction between offshore seismic exploration and whales.[3] | Marine biota monitoring guide for maritime seismic surveys | Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment.[4] | Standard Terms for Surveys at Sea. | Offshore Seismic Surveys in Greenland: Guidelines to Best Environmental Practices, Environmental Impact Assessments and Environmental Mitigation Assessments. | Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters.[5] | Environmental Guidelines for Conducting Offshore Seismic Surveys.[6] | Guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area.[7] | Environment Act. No specific requirements defined. | Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations. | Marine Seismic Surveys: Agreement on mitigation measures for the effect on cetaceans in Spanish waters and identification of sensitive areas. | Recommended monitoring and mitigation measures for cetaceans during marine seismic survey geophysical operations.[8] |
| **Year of publication / recent review** | 2017 | 2020 | 2008 | 2018 | 2016 | 2018 | 2015 | 2014 | 2021 | 2019 | 2024 | 2013 | 2011 | 2017 |
| **Type of surveys covered** | Geophysical surveys using compressed air sources and sub-bottom profilers (SBPs).<br><br>JNCC will provide case-by-case advice regarding the use of compressed air sources and electromagnetic sources such as pingers, sparkers, boomers and CHIRP systems for high-resolution surveys (HRS) as well as surveys using multibeam echosounders (MBES) in waters >200m. | Seismic surveys including 'deep penetration' surveys using compressed air sources, and 'shallow penetration' surveys using small arrays (<400 cu in) or single compressed air sources or sources such as boomers.<br><br>HRG surveys, defined as surveys using an electromechanical source that operates at frequencies less than 180 kHz, (i.e., side-scan sonar, multibeam echosounder, or CHIRP sub-bottom profiler). | Seismic surveys. | Geophysical surveys using compressed air sources. | Geophysical surveys using compressed air sources.<br><br>Statement does not apply to seismic surveys conducted:<br><br>a. On ice-covered marine waters; or<br>b. In lakes or the non-estuarine portion of rivers | Seismic surveys and other activities where recommendations are appropriate. | Seismic surveys. | All seismic surveys using compressed air sources, water-guns, sparkers, boomers in inshore and offshore Irish waters.<br><br>All multibeam echosounder (MBES), single beam echosounder (SBES), side-scan sonar (SSS) and sub-bottom profiler (SBP) surveys within bays, inlets or estuaries and within 1500 m of the entrance of enclosed bays/inlets/estuaries.<br><br>May be applied to other surveys as advised by the Regulatory Authority. Guidance document contains other | Geophysical surveys using compressed air sources.<br><br>Does NOT include surveys that utilise multibeam or sub-bottom profiling systems (pingers, chirp systems, boomers or sparkers). | Geophysical surveys using compressed air sources.<br><br>Separate, but similar protocols for military sonar activities and also coastal and offshore construction (pile-driving).<br><br>Further guidance provided in relation to offshore platforms (including wind turbine generators), controlled exposure experiments (CEEs), shipping, tourism including whale-watching, the removal of unexploded ordnance/explosive remnants of war and other acoustic devices including acoustic positioning | Seismic surveys.<br><br>Most surveys working under JNCC guidelines. Use of ADDs and PAM required. Work to be halted when marine mammals are observed.<br><br>Geophysical surveys with other sources than air guns not regulated. PAM in some cases employed. | Seismic surveys, with differing protocols depending on source array capacity:<br><br>Level 1 – >427 cu in<br>Level 2 – 151-426 cu in<br>Level 3 – <150 cu in | Seismic surveys. | Marine seismic surveys using compressed-air sources. |

[1] https://data.jncc.gov.uk/data/e2a46de5-43d4-43f0-b296-c62134397ce4/jncc-guidelines-seismicsurvey-aug2017-web.pdf
[2] https://repository.library.noaa.gov/view/noaa/23738
[3] https://www.dcceew.gov.au/environment/epbc/publications/epbc-act-policy-statement-21-interaction-between-offshore-seismic-exploration-and-whales
[4] https://www.dfo-mpo.gc.ca/oceans/publications/seismic-sismique/index-eng.html
[5] https://www.npws.ie/sites/default/files/general/Underwater%20sound%20guidance_Jan%202014.pdf
[6] https://www.gov.il/BlobFolder/guide/enviromental_info/en/Conducting_Offshore_Seismic_Surveys.pdf
[7] https://accobams.org/wp-content/uploads/2020/05/GL_Impact_anthropogenic_noise.pdf
[8] https://energeoalliance.org/wp-content/uploads/2019/07/579_new.pdf

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| | | | | | | | | specific provisions for activities including dredging, drilling, pile-driving and blasting. | | systems and acoustic deterrent devices (ADDs). | | | | |
| **Species covered** | Cetaceans, pinnipeds, turtles and basking sharks. | Marine mammals and sea turtles. | Whales, defined as baleen whales and larger toothed whales to include sperm whales, killer whales, false killer whales, pilot whales and beaked whales.<br><br>Specifically excludes smaller dolphins and porpoises. | Marine mammals and sea turtles. | Marine mammals and sea turtles with particular reference to those listed as endangered or threatened on Schedule 1 of the Species at Risk Act (SARA). | Marine mammals. | Marine mammals. | Marine mammals. | Cetaceans and turtles | Cetaceans. | Marine mammals. | Marine mammals, with focus on listed Species of Concern and differential mitigation for Species of Concern with calves. | Cetaceans | Cetaceans. |
| **Size of mitigation zone** | 500 m as standard, though alternative size zones can be proposed on a case-by-case basis. | 500 m 'Exclusion Zone' (deep penetration), which may be extended to 1500 m in special circumstances (detection of a baleen whale, sperm whale, beaked whale or *Kogia* spp.). 1000 m 'Buffer Zone' for monitoring during the pre-clearance period.<br><br>100 m (shallow penetration), with 100m buffer zone. Mitigation zone may be extended to 500 m. | 3 zones defined:<br><br>3 km observation zone.<br><br>1 km low down zone (SEL <160dB re $1\mu Pa^2$-s) ***or:***<br>2 km low power zone (SEL >160dB re $1\mu Pa^2$-s).<br><br>500 m shutdown zone. | 1000 m | 500 m | 500 m safety zone<br><br>200 m injury zone | 500 m | 1000 m (seismic, inc. sparker and boomer)<br><br>500 m (MBES, SBES, SSS, SBP) | 3000m Observation zone<br><br>500m Exclusion zone | To be determined based on modelling the power and directionality of the source, as well as local propagation characteristics. | 500 m | For Species of Concern with calves:<br>Level 1 survey – 1.5 km<br>Level 2 survey – 1 km<br><br>For Species of Concern:<br>Level 1 survey – 1 km<br>Level 2 survey – 600 m<br><br>For Other Marine Mammals:<br>Level 1 or 2 survey – 200 m | | 500 m |
| **MMO qualifications and requirements** | Dedicated: Trained personnel (via a JNCC approved training course) employed for the sole purpose of undertaking visual observations to detect marine mammals.<br><br>Non-dedicated: Trained personnel (via a JNCC approved training course) who may undertake other roles on the | Visual observers (Protected Species Observers – PSOs) must be trained and dedicated to the role. PSOs must be independent and provided by a 3rd party observer provider.<br><br>The National Marine Fisheries Service (NMFS) is required to approve PSO resumes. NMFS approves PSOs as conditional and | Trained crew, under 'Standard Management Procedures', where the likelihood of encountering whales is low. Crew members must have proven experience in whale observation, distance estimation and reporting. To be provided with briefing on EPBC Policy Statement, whale ID and | Trained professional, dedicated to sole task of observation of marine biota. Observers should hold a higher education certificate in a topic such as biology, oceanography, fisheries science, veterinary science or other compatible subject area. At least two (2) MMOs of each team must have | Qualified observers (number not detailed). | Unspecified. | Four trained MMO including two certified PAM-operators. | MMOs should be qualified and experienced.<br><br>MMOs must be familiar with Irish regulatory procedures and the details of survey licence/consent conditions.<br><br>MMOs must be dedicated to and engaged solely in monitoring the implementation of the technical guidance during the survey. | MMOs must have adequate training in detecting and identifying marine mammals and sea turtles.<br><br>Approval by the Commissioner is required, at the time of the survey application.<br><br>MMOs must have experience in supervising at least three surveys in which they were tasked with detecting | Qualified MMOs and PAM Operators, who are to have undertaken the training course developed by ACCOBAMS. | Not required. | 2 MMOs and 2 PAM Operators to be on board during all Level 1 surveys. | Unspecified total, but requirement for one trained MMO and PAM Operators per group, and need for suitable composition to allow for adequate rest between shifts.<br><br>Personnel should have received formal training, have relevant experience, familiarity with the survey locale (preferably) and have suitable | Observers should be trained to an acceptable standard. Observers may be crew, other employees or 3rd party contractors, but should have no other duties while allocated duties as a marine mammal observer. |

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| | vessel when not conducting their mitigation role (e.g., FLO or other crew members).<br><br>Where PAM is a requirement, personnel are expected to be dedicated, professional operatives which means having undergone specialist training. Those classed as 'experienced' are to possess a minimum of 20 weeks experience using PAM for mitigation and implementing JNCC guidelines within UK waters. | unconditional. Those who are conditional have undergone the relevant training but does not possess experience. Those approved as unconditional have at least 90 days at-sea experience. An unconditionally approved PSO is designated as the team-lead on offshore projects and is responsible for coordinating schedules and roles for the team, serving as point of contact etc.<br><br>PSOs may be on watch for a maximum period of 2 hours, followed by a break of at least 1 hour between watches. A maximum of 12 hours observation may be conducted by any one observer in a 24-hour period. | obligations of companies.<br><br>Trained and experienced MMOs under 'Additional Management Procedures, where the likelihood of encountering whales increases to moderate or high levels, such as in biologically important habitat. | previous experience in marine biota visual monitoring from seismic surveys of at least 100 days. Previous academic experience with marine mammals is desirable.<br><br>Team should consist of at least three (3) personnel, so that two (2) are on duty at any one time. | | | | A sufficient number of MMOs must be assigned to ensure that the role is performed effectively. | marine mammals at sea, as well as Passive Acoustic Monitoring (PAM). Preference should be given to observers that specialize in the eastern basin of the Mediterranean. | | | | identification and distance estimation skills (visual and acoustic, depending on role). | |
| **Length of pre-survey observation period** | 30 minutes (water depth <200m).<br>60 minutes (water depth >200m). | 30 minutes. | 30 minutes. | 30 minutes. | 30 minutes. | 30 minutes (water depth <200m).<br>60 minutes (water depth >200m). | 30 minutes (water depth <200m).<br>60 minutes (water depth >200m). | 30 minutes (water depth <200m).<br>60 minutes (water depth >200m). | 30 minutes in waters <300m deep, and 60 minutes in waters >300m deep | 30 minutes.<br><br>120 minutes in deep-water areas where beaked whales may be encountered. | 30 minutes. | 30 minutes. | 30 minutes (water depth <200m).<br>60 minutes (water depth >200m). | 30 minutes. |
| **Soft-start / ramp-up procedure** | <u>For sources over 180 cu in:</u><br><br>20-minute soft start from initiation to full power.<br><br>40-minute total duration from initiation to start of survey line.<br><br><u>For sources under 180 cu in:</u><br><br>15-minute soft-start from initiation to full power. | The soft start (termed ramp-up in the US) shall begin by activating a single source element of the smallest volume and continue in stages by doubling the number of active elements at the commencement of each stage. The duration shall be not less than 20 minutes.<br><br>Ramp-up can occur at any time of day or night or | Gradual increase in power over 30-minute period, commencing with a single source element. | Gradual increase over minimum of 20-minute period, and not more than 40 minutes. This period is proportional for source tests, and tests of individual source elements do not require a soft start.<br><br>The start of line should be planned to commence as close as possible to the time at which full power | Gradual ramp-up in source array volume over a 20-minute period, beginning with the activation of a single source element (preferably the smallest).<br><br>Mitigation zone must have been clear of relevant species for at last 30 minutes prior to soft start. | Ramp up over minimum 20 minutes. | Ramp up over minimum 20 minutes. Increase recommended at 6 dB/minute. | Soft start must be used for any use of a source (including testing) where the peak sound pressure level (SPL) exceeds 170 dB re: 1 µPa @ 1m.<br><br>Shall only commence during daylight hours where effective visual monitoring is possible.<br><br>Soft start shall commence using the smallest source element | Gradual increase in output starting with the smallest source element over a period not shorter than 20 minutes and not longer than 40 minutes.<br><br>Soft-start required any time the source array is re-started, excluding source testing of during use of a source with a volume <10 cu in. | Soft start required, but no specific guidance provided. | Soft start to be conducted over period of 20 minutes. | Gradual increase of the source's power, starting with the lowest capacity gun, over a period of at least 20 minutes and no more than 40 minutes. | Source level increase to follow a rate of 6 dB every 5 minutes and never exceed an increase of 6 dB per minute.<br><br>No maximum or minimum timing detailed. | Soft start should commence using the smallest source element in the array. The soft start should progress by doubling the number of active elements at each stage.<br><br>Duration should be a minimum of 20 minutes and a maximum of 40 minutes. |

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| | 25-minute total duration from initiation to start of survey line.<br><br>For electromagnetic sources, uniform ramp up in power is recommended where practical, depending on the equipment type. | times of poor visibility as long as the appropriate visual and acoustic monitoring has been conducted prior to commencement. | | from the soft start is reached.<br><br>Soft start should commence with the smallest source element. | | | | and add others gradually in consistent stages over a period of 40 minutes.<br><br>For sparker/boomer sources, the procedure should start with the lowest electrical discharge possible.<br><br>For MBES, SBES, SSS and SBP sources, where it is possible to control the acoustic output of the equipment, the output should be increased over a period of 20 minutes. Where the output cannot be controlled, the system shall be powered 'on' and 'off' in a consistent sequential manner over a period of 20 minutes. | | | | | | |
| **Visual observation requirements** | Mitigation zone to be monitored for the full duration of pre-shooting searches and soft start procedures.<br><br>Visual monitoring should be restricted to periods of good visibility during daylight hours. | A minimum of two (2) PSOs must be on duty and conducting visual observations at all times during daylight hours, including 30 minutes prior to sunrise and for 30 minutes past sunset.<br><br>During good conditions (e.g., daylight hours; Beaufort sea state (BSS) 3 or less), visual PSOs must conduct observations when the acoustic source is not operating for comparison of sighting rates and behaviour with and without use of the acoustic source and between | Continuous observation during daylight hours. | Observation to occur throughout daylight hours, but at least two (2) personnel. | An MMO is required to maintain a regular watch during the entire duration of the time that the source arrays are active and that the mitigation zone is visible. | Not specified. | | Visual monitoring is required prior to the onset of soft start procedures during daylight hours. Any breaks in activity (planned or unplanned), visual monitoring is required prior to any resumption. | At least two MMOs must be on duty at any one time. Visual monitoring is to be conducted during all daylight hours, excluding any hours of reduced visibility due to weather conditions. | Continual visual observation with a team of at least two (2) observers on watch at any one time. Equipment for visual observation is to include binoculars and big eyes. | Not specified. | Two (2) MMOs and two (2) PAM Operators to be present. One of each must be on duty at any one time. | | Mitigation zone to be monitored for 30-minute period prior to the seismic source being activated for the soft start. |

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| | | acquisition periods, to the maximum extent practicable.<br><br>PSOs are to be provided with pedestal mounted bigeye binoculars (25x150 magnification and field of view). PSOs should also have 7x50 reticle binoculars, a GPS unit and a digital camera with a telephoto lens of at least 300mm. | | | | | | | | | | | | |
| **Delay and shutdown requirements** | Soft start to be delayed if marine mammals present within exclusion zone during pre-survey observation period. The soft start can commence following a 20-minute period following the last sighting.<br><br>If marine mammals are detected within the mitigation zone whilst the source is active, there is no requirement to shut down the source. | The ramp-up must be delayed if a marine mammal or sea turtle is observed within the mitigation zone during the 30-minute monitoring period. Ramp-up can then commence following 15 minutes since the last sighting of small odontocetes, or 30 minutes for all other species including sea turtles.<br><br>During acquisition, a shutdown is required if a marine mammal (excluding delphinids) is observed/detected within the mitigation zone. While a shut down is not required for sea turtles, a voluntary pause of six (6) shots is recommended to allow the animal to float past the array. | Array to be powered down to single source element during soft start if whale enters low power zone. Array to be shut down fully if whale enters shutdown zone. Soft start can resume following 30-minute period since last whale sighting.<br><br>During operations, array to be immediately powered down or shut down if a whale is sighted in the respective zone. Resumption with soft start possible following 30-minute period since last sighting. | Soft start to be delayed if marine mammals or sea turtles within the mitigation zone prior to commencement. Soft start can commence following 30-minute period since last sighting or acoustic detection.<br><br>Source to be shut down whenever a marine mammal or sea turtle enters the mitigation zone. | The source must be shut down if the mitigation zone is breached by:<br>a. A marine mammal or sea turtle listed as endangered on Schedule 1 of the Species at Risk Act (SARA; or<br>b. Any marine mammal or sea turtle that has been identified during the environmental assessment process as a species for which there could be significant adverse effects. | Use of a mitigation gun[9] during the soft-start if marine mammals enter the 500m zone during the soft start itself, and to continue until 20 minutes after the marine mammals have moved beyond the 500m zone.<br><br>During acquisition, if marine mammals enter the 500m zone, the mitigation gun should be used until the marine mammals are confirmed as being outside of the 200m injury zone (following which full-power can resume). | | Once the soft start commences, there is no requirement to halt or discontinue source activity regardless of the visibility or presence of marine mammals within the mitigation zone. | Shutdown required for any cetacean or turtle entering the mitigation zone.<br><br>Source can be reactivated using the soft-start method after 60 minutes since the last sighting. | Delay to soft start until 30 minutes have past since last sighting (120 minutes in the case of worked in beaked whale habitat).<br><br>Source to be shut down when a cetacean enters the mitigation zone, or when aggregations of vulnerable species (e.g., beaked whales) are detected anywhere within the monitoring area. | Soft start delay, and full shut down during operations if marine mammal observed within mitigation zone. | Delay of soft-start required due to presence of species in relevant zones, as well as immediate shut-down during acquisition. | If a cetacean is detected inside the exclusion zone before the start of the soft-start, the start of the soft-start must be delayed 30 minutes (or 60 minutes in waters >200 m deep) from the last sighting or acoustic detection located inside the exclusion zone.<br><br>If cetaceans are detected inside the exclusion zone during the seismic acquisition, it must be stopped immediately.<br><br>Again there must be a waiting period of 30 minutes (or 60 minutes in waters >200m deep) for the initiation of the soft-start, from the last sighting or acoustic detection located within the exclusion zone. | Soft start to be delayed if cetaceans are present within the mitigation zone. Soft start can commence following a 20-minute period since the last cetacean sighting. |

[9] 'Mitigation gun' is a small source (one seismic source chamber), kept active as an acoustic deterrent during line turns or periods of maintenance. The intention is that for operations with short line turns (e.g. ocean bottom node surveys where the source is towed without other in-sea equipment), it can facilitate resumption of acquisition more quickly (assuming the mitigation zone is clear of marine mammals) than by ceasing source operation and going through the pre-watch and soft-start procedures.

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| | | Following the shutdown, the source may be activated again when the animals have been observed exiting the mitigation zone, or following a 30-minute observation period and subsequent ramp-up.<br><br>For high-resolution geophysical (HRG) surveys not using compressed air sources, but operating equipment below 180 kHz, no shutdown is required. | | | | | | | | | | | | |
| **Line change requirements** | Line changes longer than 40 minutes:<br><br>Source to be deactivated at end of survey line, followed by pre-shooting search and soft start procedure.<br><br>Line changes less than 40 minutes:<br><br>Source can remain active, with power reduced to 180 cu in (or as close as is feasible).<br><br>Source volumes below 180 cu in can remain at full power, but should decrease the shot-point interval (SPI) to no more than 5 minutes, reducing the SPI within the last 10 minutes of the line change back to operational timing. | Not specifically detailed, though where the source is inactive for less than 30 minutes, it can be activated again without ramp-up provided that visual/acoustic monitoring has continued during that time. For any period longer than 30 minutes, or if the source is silent for any period during hours of darkness/poor visibility, a ramp-up is required. | Array to be powered down to lowest volume when not actively collecting data. | Line changes less than 20 minutes:<br><br>Source to remain at full power.<br><br>Line changes longer than 20 minutes:<br><br>Source should be deactivated and allow for full visual and acoustic monitoring period and subsequent soft start procedure.<br><br>If the line change is longer than 20 minutes but less than 50 minutes, the 30-minute visual and acoustic monitoring period can commence during the full power acquisition at the end of the previous survey line. | Source should be shut down or reduced to single source element.<br><br>If source is reduced to a single element, visual monitoring of the mitigation zone must be in place, with shut down procedures implemented as necessary. No soft start is required when commencing next survey line. | If line change is less then 20 minutes, source to be reduced to mitigation source.<br><br>Source to cease operating if line change is longer than 20 minutes. | | Line changes longer than 40 minutes:<br><br>Source should be shut down and recommencement of the survey be preceded by a full 30-minute visual monitoring period and soft start procedure.<br><br>Line changes less than 40 minutes:<br><br>Source can remain active at full operational volume. | As UK:<br><br>Line changes longer than 40 minutes:<br><br>Source to be deactivated at end of survey line, followed by pre-shooting search and soft start procedure.<br><br>Line changes less than 40 minutes:<br><br>Source can remain active, with power reduced to 180 cu in (or as close as is feasible).<br><br>Source volumes below 180 cu in can remain at full power, but should decrease the shot-point interval (SPI) to no more than 5 minutes, reducing the SPI within the last 10 minutes of the line change back to operational timing. | Not covered. | Not specified. | Recommended to deactivate the source at the end of the survey line. However, use of a mitigation source permitted in exceptional circumstances and prior agreement. | Recommended to deactivate the source if the line change is due to me more than 30 minutes. Operations can recommence following a pre-acquisition search and soft-start procedure.<br><br>For line changes less than 30 minutes, the source should be reduced to the smallest source element only and the activation interval should be increased to 30 seconds. | Not specifically covered. However, if source is silent for 20 minutes or more, a soft start should be used to recommence survey activities. If the source is silent for less than 20 minutes, operations can recommence at full power. |
| **Night-time / low visibility requirements** | Use of PAM. Note that supplemental guidance related | PAM is required at all times when operating in | Start up using the soft start can go ahead if not more than 3 whale | Operating at night-time or during periods of | Cetacean detection technology such as PAM must be | Soft-starts to commence in daylight where possible. Where | | Activities can only commence in daylight hours where effective | PAM required for night-time monitoring and any periods of | 'High-powered' source configurations should be | Required use of PAM. | Required use of PAM during 30 minute pre-acquisition | Use of night vision binoculars by the MMOs is recommended. | Soft starts to be initiated as detailed. |

| Guideline element | United Kingdom | United States of America | Australia | Brazil | Canada | Denmark | Greenland | Ireland | Israel | Mediterranean & Black Seas | Netherlands | New Zealand | Spain | Industry Best Practice |
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| | to the use of PAM was issued by the JNCC in early 2024[10]. | waters >100 m deep. | instigated power-down or shut-down procedures have been implemented in the preceding 24 hours, or if the vessel had not been operating in the preceding 24 hours and no whales have been sighted.<br><br>Note that under 'Additional Management Procedures', soft starts may be limited to daylight hours, spotter vessels or aircraft and pre-survey research may be required. | low visibility requires PAM.<br><br>Conditions of low visibility include:<br><br>Sea state >Beaufort 6<br>Wind speed >26 knots<br><br>Fog or rain around the vessel making it impossible to view the entire mitigation zone.<br><br>Lack of visibility of the horizon, making distance calculation using reticulated binoculars impossible.<br><br>MMOs have autonomy to determine when there is a low visibility situation, even with the parameters described not being reached. | used prior to any soft start/ramp-up procedure. | not possible, PAM must be utilised. | | visual monitoring can be achieved. If effective visual monitoring is not possible, activities are to be postponed until such time that the monitoring can be conducted. | low visibility. 24-hour monitoring required.<br><br>Due to the limited ability to detect marine mammals that use ultra-high frequencies (less than 300 meters for frequencies in the range of 30-180 kilohertz), the right holder must immediately shut down or postpone the firing of air guns after any such detection in the PAM system, regardless of the strength of the signal or whether he was able to determine the direction and distance to the source of the signal. | prohibited at night or other periods of low visibility.<br><br>PAM should be mandatory at night and during periods of low visibility. | | monitoring period.<br><br>When arriving at a new location in the survey programme for the first time, the initial acoustic source activation must not be undertaken at night or during poor sighting conditions unless either:<br>• MMOs have undertaken observations within 20 nautical miles of the planned start up position for at least the last 2 hours of good sighting conditions preceding proposed operations, and no marine mammals have been detected; or<br>• Where there have been less than 2 hours of good sighting conditions preceding proposed operations (within 20 nautical miles of the planned start up position), the source may be activated if:<br>– PAM monitoring has been conducted for 2 hours immediately preceding proposed operations, and<br>– Two MMOs have conducted visual monitoring in the 2 hours immediately preceding proposed operations, and<br>– No Species of Concern have | PAM with localisation capability.<br><br>Spatio-temporal avoidance recommended for sensitive areas, and surveys only to commence in areas where there is evidence of absence of sensitive species. | Consider the use of alternative monitoring technologies such as PAM prior to commencing soft start procedures. |

[10] JNCC guidance for the use of Passive Acoustic Monitoring in UK waters for minimising the risk of injury to marine mammals from offshore activities. https://data.jncc.gov.uk/data/fb7d345b-ec24-4c60-aba2-894e50375e33/jncc-pam-guidance-in-uk-waters.pdf

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| | | | | | | | | | | | | been sighted during visual monitoring or detected during acoustic monitoring in the relevant mitigation zones in the 2 hours immediately preceding proposed operations, and – No fur seals have been sighted during visual monitoring in the relevant mitigation zone in the 10 minutes immediately preceding proposed operations, and – No other marine mammals have been sighted during visual monitoring or detected during acoustic monitoring in the relevant mitigation zones in the 30 minutes immediately preceding proposed operations. | | |
| **PAM** | As noted, PAM is often required at night and for periods of low visibility, particularly in areas of importance. PAM is required to be appropriate for the UK marine mammal species most likely to be encountered. | PAM is required at all times when operating in waters deeper than 100 m.<br><br>In the case of PAM system malfunction, survey operations can continue for a maximum of 30 minutes while issues are diagnosed. If repairs are required, operations may continue for up to two (2) hours without acoustic monitoring during daylight hours only, provided that the sea state is ≤Beaufort 4 to facilitate observations, that no marine mammals | Not required – listed as an emerging technology that may be useful during night-time or other periods of low visibility. | The use of PAM facilitates all operations, including testing, soft starts and full power acquisition.<br><br>Suggested specifications for PAM include having the first pair of hydrophones at least 200 m from the stern of the vessel, and at least 100 m between hydrophone pairs in the acoustic array and the array towed at a water depth of 20m or more.<br><br>If another configuration is to be used, a | PAM highlighted as being the primary 'cetacean detection technology' for use during night-time and periods of reduced visibility where full extent of mitigation zone is not visible. Also required if the survey is within an area where vocalising cetaceans from Schedule 1 of SARA are likely to be encountered, or those identified during the environmental assessment as being likely to be negatively impacted at a population level. | Must be used to start during hours of darkness or low visibility. | | May be recommended for some operations. It is 'broadly encouraged', but seen as not being sufficiently developed for use as a primary or sole monitoring approach for risk management purposes. | PAM required for night-time monitoring and any periods of low visibility. 24-hour monitoring required. | PAM should be mandatory at night and during periods of low visibility. | Must be used during hours of darkness or low visibility. | PAM required for acoustic monitoring during same 30 minute period prior to operations during both day-time and night-time (and poor visibility) operations. | Recommended for night-time/poor visibility in conjunction with visual monitoring using night vision. | PAM to be considered for use at night or periods of low visibility. Systems should include adequate documentation for set-up and use to include detection, classification and localisation of species. Systems should process data input from multiple hydrophones in real or near real time and should feature flexible displays to facilitate the classification of sounds, mapping displays showing bearing and distance to sounds, as well the sound source |

| Guideline element | United Kingdom | United States of America | Australia | Brazil | Canada | Denmark | Greenland | Ireland | Israel | Mediterranean & Black Seas | Netherlands | New Zealand | Spain | Industry Best Practice |
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| | | (excluding delphinids) had been detected acoustically in the previous 2 hours, that the authorities are notified and that operations without PAM do not exceed a cumulative total of 4 hours in any 24-hour period. | | justification must be presented during the environmental permitting process. This may trigger additional mitigation measures - as silencing the source whenever a marine mammal is detected (regardless its position) or to operate only during the day.<br><br>Detection should occur 24 hours per day. The PAM team should consist of at least three (3) professionals, though four (4) are recommended for better support over a 24 hour period. Additionally, two (2) of the team should have prior experience of operating PAM during seismic surveys. | | | | | | | | | | location, trackline and user defined mitigation zone. |
| **Other** | 'Areas of Importance' noted as including Marine Protected Areas (MPAs) and the deep-water area to the West of Shetland, and areas to the south-west of England. Activity in such areas may require additional measures including concurrent visual and acoustic monitoring in daylight hours. | Entanglement risk reduction details are provided for operations using underwater lines, such as some types of ocean-bottom node (OBN) survey. | Where a survey is proposed in an area that is spatially and temporally on the edge of areas considered to provide biologically important habitat, the proponent may consider implementing adaptive management procedures to manage the potential increased likelihood of encountering whales. For example, they may cease all night-time surveying if there are three | Areas of permanent and temporal restriction to activities are detailed in an annex to the guidance. | Additional Mitigative Measures and Modifications may be put into place based on the findings of the environmental assessment of the project. That may include modifications to the mitigation zone and/or variations to other measures set out in the Statement of Practice. | The right holder must contact the Danish Fisheries Association, for a more detailed discussion of the organization of the investigations, so that any inconvenience to the fishery is minimized as much as possible. A fisheries expert may be required on board.<br><br>In the case of noisy investigations such as seismic surveys, a noise recording must be made, as shown in Noise_Register_Template. The | | | The petroleum right holder must include in his application an appendix regarding the procedure and means for testing and handling air guns.<br><br>Additional guiding principles relating to the prevention of the entry of alien invasive species also included in guideline.<br><br>Additional information also provided regarding cases in which special coordination will be required in advance of | Suggested use of a minimum separation distance (not quantified) between simultaneously operating vessels. | Use of Acoustic Deterrent Device(s) (ADDs) to deter harbour porpoises used during 30-minute visual observation period prior to soft start. | | Acoustic field verification must be carried out during the first hours after the start of the operation and at each start of seismic lines that are carried out in areas whose oceanographic characteristics are markedly different from those included in the model (e.g. differences in depth) or that are carried out in markedly different periods (e.g. summer and winter).<br><br>Pre- and post-operation cetacean survey | Cetacean observations including details of monitoring effort should be made available externally for evaluation and study. |

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| | | | consecutive days on which operators experience three or more whale-instigated shut down/power down situations.<br><br>For important habitats, such as feeding areas, when concentrations of food and whales are likely to occur, an increased low power zone (e.g. 3km) may be appropriate to ensure that disturbance or displacement of whales does not occur. | | | register must be completed and returned to the Danish Energy Agency after the collection has been completed. | | | submission of the application for the survey. This includes:<br><br>• Seismic survey to be carried out less than 500 meters from fish farm – requires coordination with the Fisherman's Department of the Ministry of Agriculture.<br><br>• Seismic survey to be carried out in the declared, approved or planned reserve – requires coordination with the Nature and Parks Authority.<br><br>• Seismic survey planned to be carried out less than 500 meters from beaches and anchorage – requires coordination with the relevant authorities.<br><br>• No seismic survey will be conducted in a pelagic area defined according to the Environmental Strategic Survey as having a very high level of sensitivity. | | | | recommended in areas where there was no prior knowledge of cetacean distribution. | |

The implementation of marine mammal mitigation procedures has not been required within Norwegian waters, with the exception of the soft-start procedure, which was made a requirement from 2018 (Sivle et al., 2022). The implementation of full procedures including the use of Marine Mammal Observers (MMOs) has been voluntarily implemented by individual operators in some cases, and it is noted that Fisheries Liaison Officers (FLOs) are encouraged to report sightings of marine mammals. Since 2019, seismic surveys have been discouraged from some feeding areas for baleen whales in the Barents Sea (Sivle et al., 2020).

In addition, several time-limited exclusion zones for seismic with respect to fish spawning areas have been defined in Norway's integrated ocean management plans (white paper). These areas in the Norwegian Sea are also believed to provide some protection for marine mammals.

Further, the Institute of Marine Research provides annual update of areas and time periods when seismic is advised against with respect to fish spawning areas and fish spawning migration routes. In 2021, the Norwegian Environment Agency published a report highlighting the need for additional mitigation measures in order to reduce the risk for harmful effects to marine mammals, with a recommendation to introduce MMOs using sensor capabilities such as PAM and infrared cameras.

# 3. Planning Phase

## Baseline Data Review

Effective pre-planning measures rely on establishing detailed baseline information about the occurrence, distribution, life histories and behaviours of marine species that are likely to occur within the area where activities are planned (Nowacek et al., 2013). That baseline is generally established through a review of existing literature and data, including data held by national nature conservation agencies that may include specific information about fish spawning areas, cetacean populations and relevant management units, and relevant information about other species and protected areas. Further, data from large-scale survey initiatives can be an important input, such as the Small Cetaceans in European Atlantic waters and the North Sea (SCANS) surveys[11], ObSERVE Programme[12] and ACCOBAMS Survey Initiative[13].

Due to a paucity of existing baseline information in some regions, exploration companies have undertaken dedicated marine mammal surveys prior to seismic exploration. Examples include the collection of passive acoustic data on marine mammals using drift buoys in the Mozambique Channel (Seiche Ltd., unpublished), USV-towed hydrophone and seabed-mounted autonomous sound recorders in São Tomé and Príncipe (Pierpoint et al., 2021), and the use of static acoustic monitoring buoys to record ambient sound, vessel noise and seismic exploration activities, as well as marine mammals at the Johan Castberg oil field in the Barents Sea (Delarue et al., 2020). Such surveys need to be carefully designed, understanding that some species are not vocal at all times of the year, and some species cannot reliably be detected acoustically (e.g. pinnipeds).

Having relevant information about the species and relative sensitivities of such within an area can help to ensure that mitigation measures are tailored or adapted as necessary in order to ensure that any potential risks from exposure to underwater sound are minimised. Some regulatory authorities such as the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) in the UK

[11] SCANS-IV. https://www.tiho-hannover.de/en/clinics-institutes/institutes/institute-of-terrestrial-and-aquatic-wildlife-research-itaw/scans-iv-survey
[12] ObSERVE Programme. https://www.gov.ie/en/publication/12374-observe-programme/
[13] ACCOBAMS Survey Initiative. https://accobams.org/asi-data-presentation/

facilitate access to information and maintain a database of references relating to the distribution and abundance of marine species.

## Impact Assessment

The Environmental Impact Assessment (EIA) phase provides for a project proponent to detail all technical aspects of a potential project along with the spatial and temporal extent of activities, as well as detailed models of the potential impact zones for the sound source, detailed in the later section on *Determination of the Exclusion Zone*, from page 19. Based on an understanding of these factors, the aim of the EIA is then to assess the extent of any impacts on the environment, along with all applicable regulations that must be complied with and mitigation that can be put in place to reduce any potential impacts to acceptable levels. An EIA is a common part of the permitting process in a wide number of jurisdictions for seismic surveys, with industry guidance in place to assist industry players in ensuring that a robust EIA is developed that is based upon the best available science[14]. For the benefit of EIA practitioners and all relevant stakeholders including industry and regulators, the International Association of Oil and Gas Producers (IOGP) has also developed a web-based reference database that brings together research and other publications related specifically to underwater sound across the whole life-cycle of an oil and gas development, which includes a significant amount of work related to seismic surveys[15].

## Sensitive areas

In the UK, the JNCC guidance has traditionally considered a number of areas as 'sensitive', defined as "discrete area of important habitat for marine mammals, which may comprise, but are not limited to, areas designated as Marine Protected Areas (MPAs)" (JNCC, 2023). In the UK, the MPA network incorporates Special Areas of Conservation (SACs), Marine Conservation Zones (MCZs), Nature Conservation Marine Protected Areas (NCMPAs) and Highly Protected Marine Areas (JNCC, 2023). Other areas which remain of importance in the UK but which have no specific designation or legal protection include the deep waters to the west of Shetland as well as the south-west of England (JNCC, 2023). Within all such areas, greater scrutiny is applied during the environmental impact assessment (EIA) phase regarding the potential risks, and often there is a requirement for additional mitigation measures such as round-the-clock coverage using MMOs and PAM (JNCC, 2017).

In other jurisdictions within the OSPAR region, there are a number of MPAs established for varying species or habitat features, and with varying restrictions upon activities that can take place within them. Further levels of risk assessment may be required under relevant EU law[16] in relation to any potential impact on MPAs, including a Habitats Regulations Assessment (HRA), or where the potential for a 'significant impact' is anticipated, an Appropriate Assessment (AA). Such assessments are in place to ensure that the conservation goals and overall site integrity of the MPA are not compromised.

## Seasonal Restrictions and Measures

As noted by Nowacek et al. (2013), the best way to either minimise or potentially eliminate the exposure from geophysical surveys is to separate them in space and/or time, noting that separation in space is challenging for an inherently site-specific activity relative to highly mobile species, such as marine mammals. Seasonal restrictions are sometimes put in place for different species in order to reduce exposure to certain activities during sensitive time periods which may be important for

[14] EnerGeo Alliance EIA Handbook.
[15] IOGP Underwater Sound Research Database. https://usrd.iogp.org/
[16] The Habitats Directive. https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en

migration, reproduction, or feeding. However, this may prove challenging in areas where seasonal physical conditions in which survey operations can be safely completed overlap with these life history functions, for example in northerly latitudes with short summer seasons.

Temporal restrictions for areas known to be important for fish spawning are commonplace in various jurisdictions, including the UK and Norway in particular. In Norway, the Institute for Marine Research (IMR) advises against seismic surveys being conducted within or close to (20 nm buffer zone) spawning areas unless sound levels can be demonstrated as being below 145 dB re 1µPa 2 s SEL integrated over 10 seconds, and publishes updated advice each year (e.g., (Sivle et al., 2022), including maps to highlight the relevant areas to avoid[17]. Since 2019, the use of exclusion zones related to fish spawning were extended to include feeding areas for baleen whales, primarily in the Barents Sea. The advice and related online maps include details on the duration of relevant periods and spatial extent of these exclusions with downloadable layers for use by relevant stakeholders.

Within the Netherlands, the North Sea Agreement[18] places a number of restrictions on oil and gas activities including seismic surveys. Surveys are, where possible, excluded from taking place between May 1st and September 1st based on the reproductive season of the harbour porpoise (*Phocoena phocoena*). In the UK, seasonal measures are applied between April 1st and October 1st for work being conducted at high latitudes (defined as being north of 57° latitude). This is due to the longer daylight hours, with the requirement for a sufficiently large team of visual observation and acoustic monitoring personnel to facilitate the necessary monitoring periods (JNCC, 2017).

Spatio-temporal measures based on percentage area thresholds that can be exposed to sound on a given day and over a season have been introduced in harbour porpoise Special Areas of Conservation (SAC) in the UK (JNCC, 2020). Guidance for these areas places a limit of 20% of the area being exposed to impulsive sound on a given day, and 10% of the area over a season, using effective deterrent radii (EDRs) for different sound sources that are based on the distance at which behavioural reactions of harbour porpoises have been observed (JNCC, 2020). That same approach now forms the basis for the introduction of thresholds to reduce underwater sound in the environment to achieve 'Good Environmental Status' (GES) for Descriptor 11 (introduction of energy, including underwater noise) under the Marine Strategy Framework Directive (MSFD) (European Commission, 2017; Sigray et al., 2023).

## Population Level and Cumulative Impacts

While short term behavioural disturbances to individuals have been demonstrated, they may not have biologically meaningful impacts over the longer term (Thompson et al., 2013). However, there is an increasing understanding of the potential for sub-lethal impacts from disturbance where changes to behaviour may have an energetic burden, particularly in small species such as harbour porpoises which have high foraging rates, with potential reductions in foraging demonstrated through reduced echolocation activity (Sarnocińska et al., 2020; Wisniewska et al., 2016). Therefore, understanding the extent to which anthropogenic noise and other stressors in the environment may lead to longer-term impacts at the level of the population is an active area of research, and an important consideration in MPA management such as the threshold guidance in SACs designated for harbour porpoises in the UK, and the German Noise Mitigation Concept, both of which consider cumulative impacts from multiple noise sources.

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[17] IMR web mapping service with spawning area restrictions for seismic surveys. http://www.imr.no/geodata/geodataHI.html

[18] The North Sea Agreement. https://www.noordzeeloket.nl/en/policy/north-sea-agreement/

Early work on the potential for population level impacts included the 'Disturbance Effects of Noise on the Harbour Porpoise Population in the North Sea' (DEPONS) (Nabe-Nielsen & Harwood, 2016). Stemming from work by the National Research Council in the United States from 2005 to develop a modelling framework known as Population Consequences of Acoustic Disturbance (PCAD), the framework was further developed through research coordinated by the Office for Naval Research (ONR) and the Sound and Marine Life Joint Industry Programme (SML JIP) (E&P Sound and Marine Life Programme, 2018). The resulting Population Consequences of Disturbance (PCoD) framework considers a wider range of disturbance stressors such as climate factors, shipping density etc, and aims to establish evaluation of longer-term impacts by looking at non-lethal effects of disturbance such as energetic consequences on fecundity and responses to various stressors in individuals that may lead to changes in population dynamics (Dunlop et al., 2021). The study by Dunlop et al. (2021) specifically modelled the potential disturbance impacts of a simulated seismic survey on migrating humpback whales, noting a negligible potential effect on population growth, but identifying a number of data gaps and suggestions for field validation. Nabe-Nielsen and Harwood (2016) compared the DEPONS and early (interim) PCoD frameworks, highlighting the similarities and differences of each, but noting that the PCoD framework accounts for more sources of uncertainty as well as incorporating environmental stochasticity. The SML JIP continues to fund work to develop the PCoD framework with the aim of making it an effective risk assessment tool applicable to a broad range of activities (E&P Sound and Marine Life Programme, 2018).

## Determination of the Exclusion Zone

### Exclusion Zones

The exclusion zone, variously termed the 'mitigation zone' or 'safety zone', is a radial area around a given sound source beyond which the risk of hearing impairment in terms of permanent threshold shift (PTS) is greatly reduced due to spreading and absorption losses of the sound energy (Richardson et al., 1995; Southall et al., 2019). The presence of protected species within the exclusion zone will result in some mitigating action to be implemented, such as a delay to the activation of the sound source, or the cessation of the sound source during acquisition (Compton et al., 2008). However, there may be multiple zones with varying terminology depending on the jurisdiction, each with different actions triggered when breached by protected species (e.g. Australia, see Table 1). A typical mitigation zone range is 500m radial distance from the centre of the source array, though as detailed in Table 1, this does vary with jurisdiction, and can vary based on the outputs of modelling to understand the distance at which exposure criteria are met. A 500m zone for a modern 3D seismic survey is typically larger than extent of the threshold SEL contour at which PTS would occur (Southall et al., 2019).

### Sound source modelling / verification

An important element of the risk assessment process introduced in the section on Impact Assessment on page 17 is the modelling of the sound source in order to gain an understanding of the source level and characteristics (i.e., how loud the sound is at the source, measured in decibels [dB]), together with the frequency/frequencies generated by the sound) (Goertz et al., 2013). Significant work has been undertaken by industry within the Exploration & Production Sound and Marine Life Programme (SML JIP) to characterise marine compressed air single sources, clusters and arrays, including work by Prior et al. (2021), and Sidorovskaia & Li (2022). There has been less work on high-resolution sources (e.g. sub-bottom profilers including boomers and sparkers), though notable work includes studies by Crocker et al. (2019) and Ruppel et al. (2022).

Proprietary models are typically used to compute the array source level, including Gundalf[19] and Nucleus[20]. These models are accurate over the dominant frequency range of seismic sources (1-1000 Hz) (Tashmukhambetov et al., 2008). Strategies have been developed for the estimation of higher frequency components of the source output (Macgillivray, 2019). Typically, a seismic company will provide modelling results for their proposed array that will include the waveform and amplitude spectrum of the pulse and the array directivity over the frequency range modelled.

Common outputs of the Gundalf and Nucleus models include the following:

- Source directivity, depicting how source levels may vary with direction
- Wave form of a single seismic array pulse, showing the peak sound source levels
- Frequency spectrum of the pulse, highlighting the frequencies that contribute to the source level
- Maps of the sound pressure level (SPL) and sound exposure level (SEL) surrounding the source that can be used for the determination of exclusion zones.
- Simulation of the sound output levels of a soft-start procedure.

The choice of sound metric is important in terms of relating the potential impacts of industrial sound on marine life. While the SPL, generally reported as peak or peak-to-peak, characterises the amplitude of the sound and is more relevant to the potential for physiological injury, SEL considers both the received level and the duration of exposure and the auditory frequency weighted SEL integrated over a given duration has become the most widely used metric (Martin et al., 2019). SEL can be calculated relevant to an individual sound pulse such as an individual seismic source signal, or the strike of a construction pile, denoted by $SEL_{SS}$ (single-strike). When integrated over a number of pulses or time period, this provides an estimate of the cumulative SEL, denoted by $SEL_{CUM}$, and is more relevant to more continuous source activation methods such as those described in the later sections (*Modern acquisition methodologies* and *Marine vibrators),* such as continuous wavefield acquisition and marine vibrators, which produce lower levels of energy over a longer period of time. However, the greatest contributor to SEL for an impulsive, mobile source (i.e., a more conventional seismic survey) is the pulse at the closest point of approach (CPA) (Martin et al., 2019), so SPLpk is typically a more informative metric in these cases.

These models include an analytical sound propagation model that allows estimation of the decay of the sound level with distance and relate it to the marine mammal exposure criteria by Southall et al. (Southall et al., 2019). Output can also be filtered to simulate the hearing range of different functional groups of marine mammals, as proposed by Southall et al. (2008). For cases of strongly varying bathymetry or strongly varying acoustic properties, output from the above models (in particular source signatures and directivity functions) can be used as input for numerical sound propagation modelling (Tashmukhambetov et al., 2008; Wladichuk et al., 2018).

The seismic source array is a distributed, rather than point source, meaning that in close proximity to individual chambers (<75m), the peak of each source element will arrive at the measurement point at a different time (Caldwell & Dragoset, 2000). Only in the 'far field' (>250m from the source) will the pressure peaks from the individual source elements have coalesced to form a coherent pulse (Caldwell & Dragoset, 2000; Gisiner, 2016). Back calculation from the far field source level can therefore be inaccurate, and work has been undertaken to compare field measurements and modelled data, demonstrating that actual source levels can be lower than models may suggest (Fontana et al., 2018).

[19] GUNDALF is a product of Oakwood Computing. https://www.gundalf.com/
[20] NUCLEUS is a product of PGS. Nucleus+ | PGS

# 4. Geophysical Technology

## Survey Platforms

### Seismic Survey Vessels

The global seismic survey fleet of vessels (those actively deploying sources and receivers) is a small (106 vessels as of 2021[21], compared to over 5000 container vessels in 2022[22]), modern and highly specialised fleet. While the majority are acquiring data on a commercial basis for exploration purposes, seismic vessels are also operated by research institutions in order to undertake dedicated scientific research. Such operations follow the same mitigation as for commercial projects, and as detailed in their own environmental risk and impact assessments. The number of vessels active at any one time can fluctuate depending on market dynamics, impacted by factors such as oil price and overall demand, as well as newer sectors such as Carbon Capture and Storage (CCS). The fleet includes vessels that have been purpose-built for deploying large spreads of in-sea equipment for acquiring seismic data through the use of relevant source and receiver systems. 'Surface seismic' relies upon the towing of large numbers of hydrophone streamers (in the case of 3D seismic), with up to 24 streamers being towed which are several kilometres in length. While vessels vary in design and specification, a typical 3D seismic vessel will be around 80-100m in length and anywhere from 20 and up to 70m in width. 2D seismic vessels, which tow a single hydrophone streamer are typically smaller.

*Figure 1; 3D seismic vessel with towed source and receiver spreads behind.*

Ocean bottom seismic, whereby receiver cables or nodes are placed on the seabed are typically multi-vessel operations, involving a specialised vessel for deployment of receiver equipment, and a smaller 'source vessel', operating the seismic source. Ocean bottom cable systems are similar to towed streamers, but are placed on the seafloor typically over a producing hydrocarbon field. Ocean bottom nodes are typically small (<1m) seismometers that are placed on the seafloor in a network. In each

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[21] Global seismic vessel fleet at pre-Covid level as energy transition jobs ramp up. https://www.offshore-energy.biz/global-seismic-vessel-fleet-at-pre-covid-level-as-energy-transition-jobs-ramp-up/

[22] Statista – number of container ships in the global merchant fleet from 2011 to 2022. https://www.statista.com/statistics/198227/forecast-for-global-number-of-containerships-from-2011/

case the source vessel will acquire survey transect lines over the seafloor equipment which records the data. A source vessel in this instance may be a 'vessel of opportunity', such as a platform supply vessel or similar, equipped with a modular seismic source system. Nodes are generally deployed together, linked via rope, or individually by Remotely Operated Vehicles (ROVs). There are also autonomous nodes in development by a number of companies, which are able to be positioned and recovered automatically (Tsingas et al., 2019).

## Automated Surface and Underwater Vehicles

Significant advances have been made with marine autonomous systems, including Autonomous/Unmanned (or Uncrewed) Surface Vehicles (ASVs/USVs) and Autonomous Underwater Vehicles (AUVs). The range of civil and military applications has increased dramatically as capabilities have increased in terms of relevant instrumentation and safe navigation (Bai et al., 2022; Hu et al., 2022; Wynn et al., 2014). Unlike ROVs, AUVs and A/USVs are untethered, self-propelled and able to significantly extend the range over which data may be acquired (Wynn et al., 2014). The payloads of autonomous systems can include a range of geophysical sensors, including multibeam sonar (MBES), sub-bottom profilers (SBP), sidescan sonar (SSS) and magnetometers, all typically utilised in high-resolution mapping and investigation (Wynn et al., 2014). There are an increasing range of companies manufacturing and deploying both AUVs and A/USVs commercially for a broad range of uses including habitat mapping (Shields et al., 2020), minerals exploration (Offshore Technology, 2023), infrastructure monitoring and inspection (Galavazi & Veerhuis, 2022) and bathymetric survey work (Water et al., 2023).


*Figure 2; Example of an Unmanned Surface Vessel (USV). Courtesy of Fugro.*

Autonomous systems present significant advantages in terms of reducing the exposure of crew to the offshore environment and associated risks during operations, reducing carbon emissions and facilitating faster data acquisition from challenging locations (Galavazi & Veerhuis, 2022). The development of A/USVs have necessitated work to ensure their safety in relation to collision regulations and surface navigation, and regulatory frameworks have limited the size of uncrewed vessels to below 12m (Galavazi & Veerhuis, 2022; Hu et al., 2022), but have also presented concerns regarding interactions with marine life. Marine mammal monitoring requirements in the United States for example have been extended to include protocols that specifically include measures for monitoring around A/USVs, including the provision of high-definition (HD) camera technology on both the A/USV and mother ship from which marine mammal observers (MMOs) are required to monitor the live video feed (BOEM, 2021). The scale and use of autonomous, uncrewed vessels is likely to increase due to the safety and cost savings that can be made, with industry already preparing full-scale, multi-role vessels.

## Exploration and reservoir monitoring surveys

Seismic exploration surveys are required to identify potential hydrocarbon resources, generally moving from large scale 2D ‘regional’ surveys which identify general areas of interest, and then more focused 3D surveys which help to better identify potential drilling targets, reducing the risk of drilling dry wells. Once a hydrocarbon field has been developed, regular monitoring may be undertaken at specific intervals to understand the changes and depletion within the hydrocarbon reservoir. This is achieved through ‘4D’ or ‘reservoir monitoring’ surveys, which can be undertaken both using conventional towed streamer methodologies, ocean bottom techniques such as Ocean Bottom Nodes (OBN), or through the installation of permanent seabed cable systems over the reservoir, often termed Permanent Reservoir Monitoring (PRM) or Life of Field Seismic (LoFS).

The same techniques are applicable to the identification and monitoring of geological structures for the storage of usable gas resources including natural gas and hydrogen, as well as waste products such as carbon dioxide ($CO_2$) and radioactive materials. Carbon Capture and Storage (CCS) is a climate mitigation technique, and important growth area in the OSPAR region and beyond, with seismic surveys as one of the key tools that can be used to locate storage facilities and monitor the movement of $CO_2$ within the storage facility over time, for which OSPAR has comprehensive guidelines related to risk assessment and the management of $CO_2$ storage[23].

Marine seismic acquisition methods and technologies are described in detail within a comprehensive overview published jointly by the International Association of Oil and Gas Producers (IOGP) and EnerGeo Alliance (then the International Association of Geophysical Contractors – IAGC)[24].

### *Standard seismic sources*

Since the 1970’s, the ubiquitous seismic source has been the compressed-air source commonly known as the ‘airgun’, which replaced the use of dynamite or nitrocarbonitrate explosive sources and ‘water guns’ (Landrø & Amundsen, 2010; Parkes & Hatton, 1986). Airguns are produced in a range of sizes based on the volume of air that they can hold, from <1l volume to >20l volume, with sizes generally expressed in cubic inches ($in^3$), rather than metric measurements. Compressed air sources are typically arranged in arrays of anywhere from 20-50 individual source elements in order to increase the signal strength to be able to penetrate a given seafloor geology for the purpose of understanding the subsurface (Dragoset, 2000; Parkes & Hatton, 1986). A typical array is towed in dual-source configuration, with each source array being made up of three sub-arrays (see Figure 3).

[23] OSPAR Guidelines for risk assessment and management of storage of $CO_2$ in geological formations: https://www.ospar.org/documents?d=32760

[24] An overview of marine seismic operations: https://www.iogp.org/bookstore/product/an-overview-of-marine-seismic-operations/

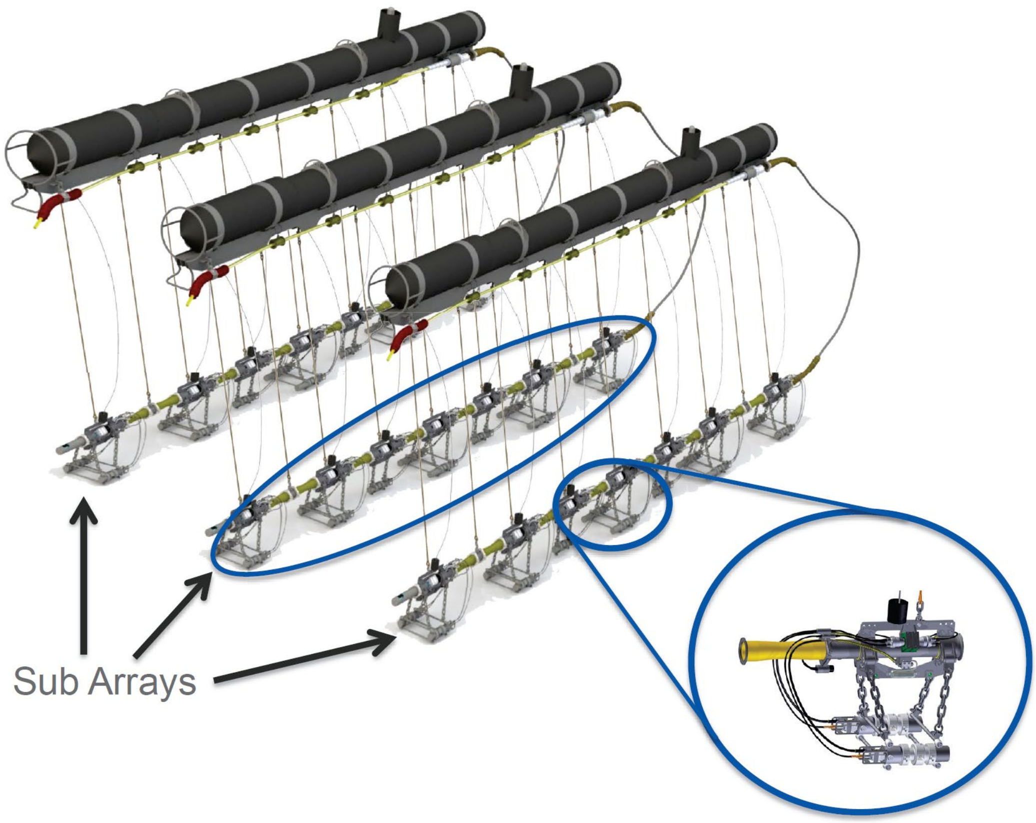


*Figure 3; a typical seismic source array, comprised of three sub arrays. Courtesy of PGS.*

The three sub-arrays making up one source array are then activated alternately with the other source array (termed 'flip-flop') approximately every 10-12 seconds during the acquisition of data along a survey line, depending upon the survey objectives. Arrays are generally pressured with compressed air to between 2000 and 2500 psi (~140-170 bar). The dominant frequencies of a seismic source signal are typically below 100 Hz (Gisiner, 2016), with low-frequency pulses of most use for deep geological targets and imaging below challenging geological layers such as basalt. High-frequency sound is present at lower amplitudes, though can be exacerbated by cavitation caused by reflection of the sound pulse at the sea surface (Landrø et al., 2011).

## High-resolution surveys

Characterising the seabed and the shallow subsurface is critical to the planning and engineering design processes for a broad range of marine infrastructure, including hydrocarbon production platforms, pipelines, offshore wind turbines, cable routes and so on. This requires a broad range of high-resolution geophysical (HRG) survey instrumentation, selected based on varying factors including water depth, geology and the purpose for the survey which will dictate the depth of data that are required. This range of systems is largely comprised of electro-acoustic sources (as opposed to compressed-air sources), as well as non-acoustic sources such as magnetometers. Often used in combination, this category of sources includes multibeam echosounders (MBES), sidescan sonar (SSS), single-beam echosounders (SBES), sub-bottom profilers (SBPs) and shallow multichannel seismic systems including sparkers, boomers and bubble-guns (Ruppel et al., 2022).

The variety of systems are also deployed in variable ways, with hull-mounted, pole-mounted, ROV/AUV/USV mounted and towed options available for some, while sparkers and boomers are typically towed in combination with scaled down receiver arrays (when compared with deep-penetration seismic) (Widmaier et al., 2023). Most HRG instruments are high-frequency and highly directional, with some unlikely to impact marine mammals due to the transmission frequency being beyond the hearing range of most species (Ruppel et al., 2022), though research has shown audibility of sub-harmonic frequencies produced by some commercial echosounders (Deng et al., 2014). Work to understand the characteristics of the range of sources used in acoustic surveys has been undertaken by Natural Resources Wales (2020). There are a number of knowledge gaps associated with this broad range of devices, though work by Ruppel et al. (2022) has sought to categorise marine sources into tiers from those that are likely to result in incidental 'take' per United States laws and policies[25] (Tier 1) to those, the characteristics of which in terms of frequency, power output and directivity are unlikely to result in incidental take (Tier 4), including MBES, SSS, most SBPs, some low-powered sparkers and boomers as well as acoustic positioning systems. Incidental 'take' under the US Marine Mammal Protection Act (MMPA) distinguishes between 'Level A' harassment, which has the potential to result in injury, and 'Level B' harassment, which refers to disturbance of essential behaviours such as feeding, breeding etc. The Ruppel et al. (2022) study compared sources to the threshold relevant to Level B harassment, with those sources assessed as Tier 4 being rendered de minimis by the factors considered.

## Methodological and Technological Abatement

While achieving the geophysical objectives of a given survey will require a source signal that is capable of deriving data to illuminate geological targets at a given depth and geological setting, modern acquisition techniques, technologies and advanced processing techniques can reduce the amplitude of the source, as well as focus the bandwidth more on those frequencies of most use. Described below are a number of modern acquisition methodologies, newer source variants and other sources under development which offer a form of abatement.

The variety of means to provide abatement of sound input through modern acquisition techniques, engineering modifications and alternative technologies as described here is the subject of ongoing review by participants in the Global Alliance for Managing Ocean Noise (GAMeON)[26]. An initial workshop discussed a number of the alternative methodologies and technologies described above, with discussion of the advantages, disadvantages, costs and relative technology readiness levels published in a subsequent report (Lee et al., 2023).

### Modern acquisition methodologies

Previous advances in acquisition methods focused on efficiency through increasing the number of receivers deployed, which increases the separation of survey lines, acquiring more data per kilometre sailed. This reduces exposure for crew, reduces the overall environmental footprint and can result in reduced costs. The method of source use through the deployment and activation of a typical dual-source array for 3D seismic had not changed significantly until more recently, when the use of multiple sources became more widespread. Using multiple sources has previously been challenging, but with improvements in receiver technology and the ability to record and de-blend data from simultaneous

[25] As defined within the US Marine Mammal Protection Act: https://www.fisheries.noaa.gov/national/laws-and-policies/glossary-permits-protected-resources

[26] GAMeON. https://www.globalallianceoceannoise.org/

sources, use of the technique has gained acceptance (Langhammer & Bennion, 2015; Widmaier et al., 2019, 2020, 2021).

Multiple sources, in effect, divide the existing in-sea source equipment typically towed as dual sources made up of three sub-arrays into more, smaller sources by cubic volume. Each individual source is then activated more frequently, reducing the interval between data sampling points, creating greater spatial resolution both in-line (due to reduced activation interval) and cross-line (due to the increased number and physical separation of sources) (Widmaier et al., 2021). The use of three, four, five and even six sources can be utilised, and has been shown to increase survey efficiency and data quality. The size of the individual arrays can be reduced to in the region of 5-10 individual elements, ranging from ~400-1500 $in^3$ per active array, reducing peak sound level outputs significantly (Widmaier, 2022).

The use of multiple source activation has also been extended to that of individual source elements, whereby a continuous source wavefield is emitted and recorded (Hegna et al., 2018). Such methods include 'eSeismic' and 'popcorn' seismic, with each representing a method of continuously recording seismic data along a sail line, with single source elements operating continuously in a pseudo-randomised pattern (Abma, 2018; Hegna et al., 2018). As peak sound pressures relate to single elements only, the SPL is ~20-22 dB lower than for conventional methods, with a reduction in SEL of ~8-9 dB (Long et al., 2019).

### *Source clustering*

Strengthening the lower frequency part of the seismic source output signal without increasing, or even lowering high-frequency content can be achieved by other means than physical modifications to sources. Hopperstad et al. (2012), used the physical clustering of source elements in such a way to create a 'hypercluster' that creates a frequency-locking response whereby the released air from clustered source elements behaves as a large oscillating bubble with a resonant frequency of a much larger individual element. This reduces the need for larger physical source elements, is operationally straightforward to achieve, and has been shown to result in an uplift in the low resonant frequency of as much as 10 dB, while reducing the amplitude for frequencies above 10 Hz (Elboth et al., 2022b).

## Available Alternative Source Technologies

There are a number of alternative seismic sources available on the market which aim to reduce the high-frequency content of the source signal and/or lower the SPL and SEL, while retaining the essential attributes for achieving geophysical objectives. The potential for integration of these technologies by companies will vary depending on cost, compatibility with existing systems and planned maintenance and renewal periods.

### *Bandwidth limited sources*

While the high-frequency content of the signal from a compressed air source is low, concerns for species such as harbour porpoises and others that use high frequencies have led to some developments which aim to reduce the high-frequency content of the seismic pulse further. One method has been to redesign certain parts of compressed air sources such that the bandwidth is altered to attenuate the high-frequency output (Supawala et al., 2017; Tellier et al., 2021).

*Figure 4; a traditional Bolt 1900 LLXT seismic source (left) and Bolt 'eSource' (right). Courtesy of Teledyne Bolt.*

Shown in comparison to a standard source in Figure 4, the ‘eSource’ has a teardrop port shape through which the compressed air is released, which combined with precise control of the internal piston speed results in a slower rate release of the air (Coste et al., 2014; Supawala et al., 2017). The power spectral density (PSD) for frequencies above 120 Hz is significantly reduced from that of traditional sources and can be as much as 30 dB lower for frequencies above 600 Hz (Li & Bayly, 2017). Modelling comparisons between the two Bolt sources show that the SEL (dB re 1µPa2·s) for the eSource can be 4.2 dB lower at 1 km and 5.3 dB lower at 2 km (Li & Bayly, 2017).

A similar source known as the ‘Bluepulse’ has achieved a similar reduction in high-frequency signal content using modifications to internal parts of the source chamber (Tellier et al., 2021). Modelled data show that there is a significant reduction of 10 to 20 dB in both SEL and SPL for frequencies above 128 Hz when comparing a full array (4,180 in$^3$) of conventional and Bluepulse source elements (Tellier et al., 2021).

In each case, there is no demonstrable reduction in imaging capability for the relevant geological targets, and the modifications to the sources do not change the manner in which they are deployed, enabling upgrade and replacement over time where not cost-prohibitive.

Previously known as the Low Impact Seismic Source (LISS), a type of source that is operated at a much lower pressure than standard compressed sources has been further developed and commercialised and is now known as the Tuned Pulse Source (TPS) (Chelminski et al., 2019; Ronen & Chelminski, 2017; Tellier et al., 2021). The TPS, shown in Figure 5, is a large-volume source, currently being tested in a 26,500 in$^3$ configuration, but operated in the pressure range of 600-1000 psi (~40-70 bar). More energy is released by a TPS, but over a longer period than a conventional source, resulting in a lower SPL and with a lower rise-time (Tellier et al., 2021). The TPS has a lower fundamental frequency than traditional sources (2.8 Hz compared to 7-8Hz) and produces a weaker signal at 150 Hz by 30 dB (Tellier et al., 2021).

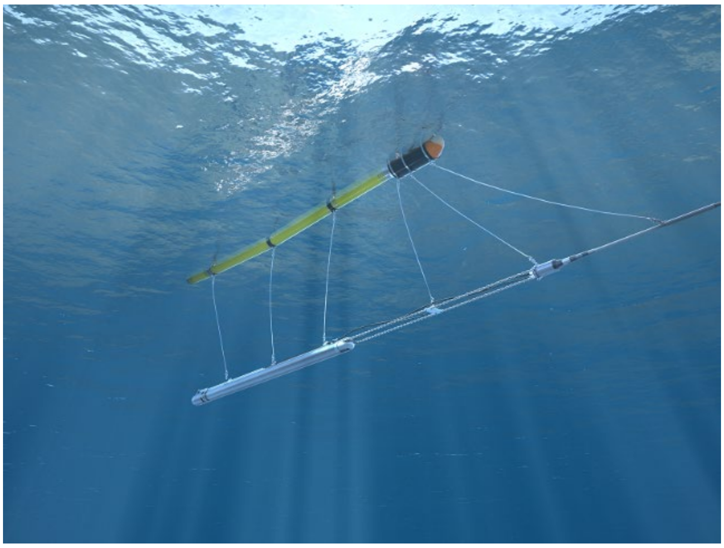

*Figure 5; the Tuned Pulse Source (TPS). The Tuned Pulse Source (TPS™), an innovative low frequency broadband marine seismic source designed to master complex geologies (courtesy of Sercel).*

Similar to the TPS is a source that has been used commercially[27] known as Gemini, which is a large volume source designed to enhance the signal to noise ratio of the low frequencies with comparatively low high-frequency output (Udengaard et al., 2023).

## Source Technology in Development

Further alternative systems have been in development for some time, with a focus on a number of different marine vibrator systems, as detailed below. They are not available at commercial scale at the time of writing, with ongoing trials prior to any going into production if found to be viable.

### *Low frequency source*

A further source variant that is not characterised as an alternative to traditional seismic sources and is not a compressed air source, but rather a source developed to improve imaging at low frequencies was developed by a consortium led by BP. Known as the 'Wolfspar' unit, it is focused on imaging in the 1-2 Hz range. Two field trials have been conducted in the Gulf of Mexico to date (Brenders et al., 2020).

### *Marine vibrators*

Marine Vibrator systems produce controlled frequency modulated continuous acoustic signals through volume displacement of water using a vibrating plate or shell. As opposed to a traditional compressed air source, the duration as well as the signature of the marine vibrator energy can be customized, providing a range of options to configure the source output. Surveys can also be more easily tailored to the geophysical objectives of planned surveys. It is possible to select which frequency band to emit, at what SPL and SEL. Operations could also be flexible in real time, in terms of implementing changes to the frequency range and other characteristics of the sound during a survey with MV than with traditional compressed air sources.

[27] 'Supermajor' to deploy ION's Gemini tech in 3D acquisition in Mediterranean Sea: https://www.offshore-energy.biz/supermajor-to-deploy-ions-gemini-tech-in-3d-acquisition-in-mediterranean-sea/

A recent paper published by Matthews et al. (2020), provides a modelling comparison of the potential effects on marine mammals from sounds produced by Marine Vibroseis (MV) compared to traditional compressed air sources. The goal of this study was to compare the signal characteristics and estimate the marine mammal exposures associated with each technology. In summary, MV units release energy over a longer time with modelled results showing considerable reductions in peak-to-peak SPL and SEL (Duncan et al., 2017; Matthews et al., 2020), likely resulting in lower potential impact ranges. However, more recent work by McQueen et al. (2024) showed potentially greater levels of disturbance to the behaviour of cod from the activation of MVs due to the continuous sound than from traditional seismic sources. This highlights the further need for assessment of the potential environmental impacts and consideration of appropriate mitigation for these units.

A system now marketed as the SAE Marine Vibrator[28] is a shallow-water system (capable of working in water as shallow as 1m) that was developed over a period of over 20 years with involvement from a variety of companies during that time, originally acquiring test data in Louisiana in 1996 (Pramik et al., 2015).

TotalEnergies, ExxonMobil and Shell have sponsored the Marine Vibrator Joint Industry Project (MV JIP) since 2011, supporting the development of three separate marine vibrator technologies. Currently the MV JIP are working exclusively with General Dynamics Applied Physical Sciences (APS) to develop and commercialise a vibrator source known as the Integrated Projector Node (IPN) powered by an electromagnetic system. The IPN system underwent open water verification trials in September and October of 2022 by acquiring a 2D seismic line over ocean bottom receiver nodes, showing positive results in terms of imaging (based on fast-track processing results), comparable with acquisition using traditional compressed air sources (Alfaro et al., 2023; Roy et al., 2023).

Shearwater Geoservices, supported by the Norwegian Research Council and Equinor are developing a hydraulic based MV system known as the Broadband Acoustic Seismic Source (BASS) (Elboth et al., 2022a). The system has been tested statically as it is not yet built into a tow body and deployed during experimental trials to study cod behaviour in relation to exposure to acoustic sources (Sivle et al., 2023). The aim is to have had a system ready for a 3D survey trial in 2023 (Elboth et al., 2022b) with results anticipated in 2024.

Key technical and operational challenges remain when it comes to developing a fully integrated acquisition solution, which is safe and robust, including the launch and recovery system, array configuration set-up, positioning, reliability, among others. Processing challenges such as deblending of simultaneously acquired data to separate the overlapping signals from the more constant source are a topic of ongoing research (Guitton et al., 2023).

A key area of uncertainty and continued research interest relates to the potential impact of MV output signals on marine mammal auditory masking and behavioural responses particularly for low-frequency mammals (Weilgart, 2023). Behavioural response field trials focused on blue whales having been planned for 2024 under the SML JIP.

### Vessel as a Source

The feasibility of using the acoustic wavefield generated by a vessel as a sound source (i.e. with no additional seismic source equipment deployed) for subsurface imaging is being explored (Hegna, 2022). The potential for such a method would remove the introduction of impulsive sound during such

[28] SAE Marine Vibrator: https://saexploration.com/marine-technology/

a survey, reduce costs for operators, as well as other potential advantages for making frequent monitoring over producing reservoirs or carbon storage locations more practical (Hegna, 2022). The acoustic wavefield of the vessel needs to be characterised and the location of the source understood, which can vary with acquisition configuration. Tests with the vessel sailing over a towed array of hydrophone streamers showed the best results in terms of the estimation of the wavefield over a wide bandwidth, and recorded seismic data was of a similar quality in the shallow geology (first few hundred metres) to that acquired with a traditional compressed air source at the given test location (Hegna, 2022).

# 5. Operational Mitigation Measures

## Pre-acquisition search

As detailed within Table 1, many jurisdictions require visual observation and, where applicable, an acoustic monitoring period of 30 minutes duration be carried out prior to the activation of the seismic source. This systematic observation is a fundamental element of a mitigation strategy or process to ensure that the mitigation zone is clear of marine mammals or other protected species before the seismic source is activated. Visual observation may be the only means of detection for species such as turtles which can be challenging to observe with increasing sea state. Other protected species which may not be conspicuous at the surface may only be observed opportunistically.

Deep-diving species such as sperm whales and beaked whales are known to forage for longer periods than 30 minutes. In habitat where such species may be encountered, including waters deeper than 200m, the pre-acquisition search is extended in some guidelines to 60 minutes, as is the case in the UK, Ireland and in the Mediterranean per the ACCOBAMS guidelines (ACCOBAMS, 2019; DAHG, 2014; JNCC, 2017).

## Soft-Start/Ramp-Up

The soft-start process, also termed the ‘ramp-up’ in jurisdictions such as the United States, is the gradual increase in acoustic output from the source array over a defined period of time until full operational power is achieved. Once at full power, the vessel should be at the beginning of the relevant survey line, in order not to extend the emission of full array output unnecessarily (JNCC, 2017). The time period over which the soft-start is achieved varies a little depending on the jurisdiction, but as shown in Table 1, it is generally no less than 20 minutes and no more than 40 minutes. The soft-start begins with the activation of the smallest element in the array, and while some guidelines ask that the output increase in 6dB steps every 5 minutes (e.g. Spain), the most common practice is to double the number of active elements at each stage (IOGP/IAGC, 2017). For sources such as sub-bottom profilers, it is generally required that there be some form of soft-start by increasing the power, where feasible.

The premise of the soft-start is that animals will move away as the sound becomes more aversive, and before reaching levels above thresholds that may have the potential to result in auditory damage (Stone et al., 2017). It is a ‘common-sense’ measure which is straightforward to implement, with analysis of data collected by MMOs and PAM Operators within UK waters having shown that there are significantly reduced detection rates during the soft-start, indicating that animals do move away (or stop approaching) as the sound level increases, therefore reducing exposure to higher sound levels (Stone et al., 2017). Further work to study the effectiveness of this measure was conducted as part of the large-scale Behavioural Response of Australian Humpback whales to Seismic Surveys (BRAHSS) study which also showed that humpback whale deviated course from an active source undergoing soft-start resulting in an increased distance from the source vessel, indicative of an avoidance response (Dunlop et al., 2016).

Soft-starts are generally encouraged to be undertaken in daylight hours in order to facilitate the visual pre-watch, though many jurisdictions allow the use of PAM prior to a soft-start in order to facilitate survey operations during hours of darkness or poor visibility. Other guidelines, such as those from Ireland, do not allow soft-starts outside of daylight hours, which can have the unintended consequence of extending the time of the vessel and sound source in the field, ultimately increasing the potential number of animal interactions and emission from the survey vessel(s).

A soft-start is generally required before each use of the source array, with some exceptions for testing of source elements, or for the use of very small sources (e.g. <10 in$^3$) (JNCC, 2017).

## Line Changes

Surveys are generally conducted along a pre-determined plan of survey line transects. While it can be beneficial to sample a great range of azimuths in some challenging geological settings (Hager, 2010), a more typical operation will record data along the survey line and will then transition from one line to another during an often-lengthy line change. As shown in Figure 5, due to the scale of the in-sea equipment, the vessel will change on to a line perhaps several kilometres away and acquire survey lines sequentially in a ‘race-track’ pattern that is designed to acquire the survey in the shortest time, depending on any other spatial restrictions or adjustment for weather such as strong currents.

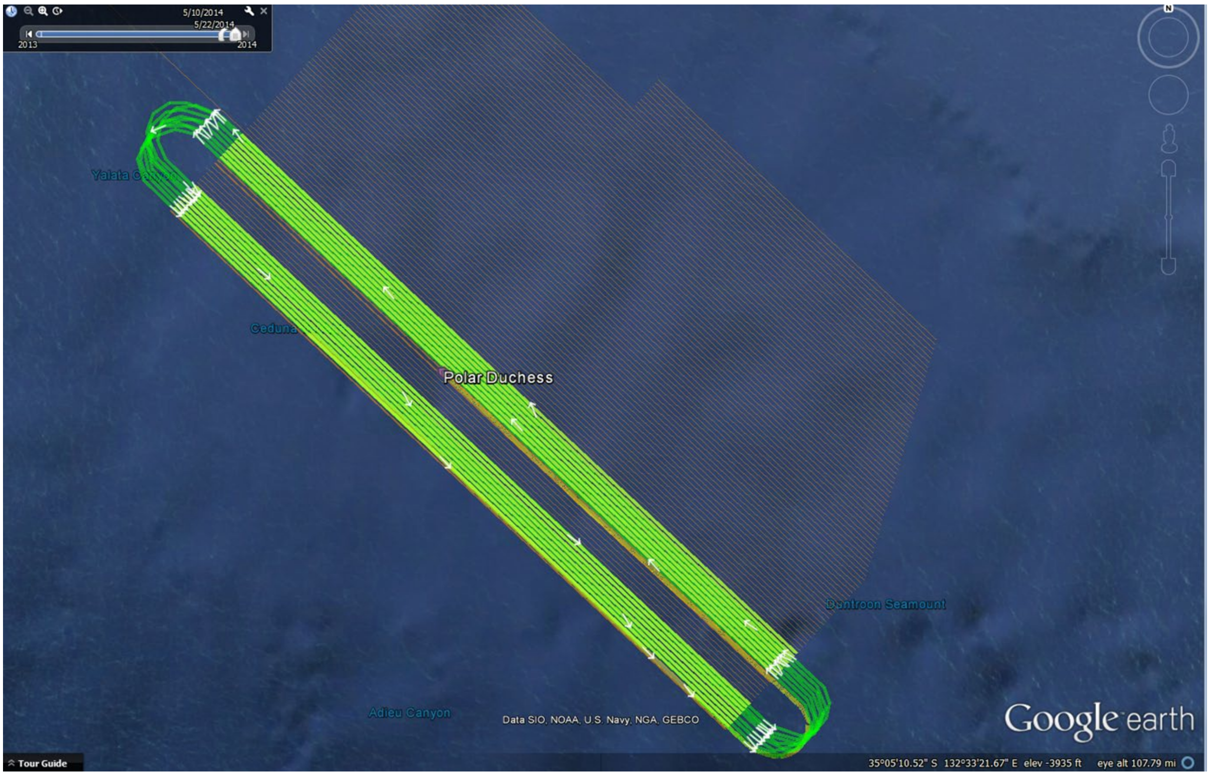


*Figure 6; example of typical acquisition pattern during a 3D survey, where the vessel is acquiring lines alternately in a south easterly and then north westerly direction.*

As the vessel is moving at only ~4kts, a line change can take well over an hour to complete. The advice in most jurisdictions therefore is that the sound source should not be active during this transition, and that pre-acquisition monitoring and a soft-start should precede the use of full operational source volume on the next survey line. In the UK for example, the advice is that the source should cease activation if the line-change is forecast to take more than 40 minutes (JNCC, 2017). If the line change is likely to be less, then often the source can remain active, but may be required to be at a lower volume or a reduced activation interval. OBN surveys typically have quite short line changes, as the receivers are on the seafloor and the vessel is therefore towing only a sound source over a relatively small area.

## Marine Mammal Observers (MMOs)

Marine Mammal Observers (MMOs) are the visual observers that are deployed onboard the seismic vessel to visually monitor the exclusion zone for protected species, and to order the implementation of mitigation measures if they are present. Variously termed Protected Species Observers (PSOs), Marine Fauna Observers (MFOs) and Marine Mammal and Seabird Observers (MMSOs), these personnel are typically trained via an appropriate short-course accredited by an agency such as the JNCC[29]. There are no pre-requisites to training as an MMO in most cases, though it has become a common expectation that personnel have an educational background in marine biology or a related field, with some guidelines (e.g. ACCOBAMS) starting to implement a pre-requisite such as degree-level training.

MMOs are generally equipped with binoculars to aid identification, as well as to improve distance estimation. Binoculars with integrated reticles allow for the calculation of the distance between the observed animal and the observer based on knowing the eye-height of the observer and the vertical angle between the animal and the horizon, based on standard formulae to convert reticle values to vertical angles (Lerczak & Hobbs, 1998). The same can be achieved using a range-finding stick which can be prepared for the specific eye-height of an observer and known platform such as the bridge deck of a particular vessel. The JNCC provide a guide for MMOs to make such a range-finding stick which is a common tool for use with the naked eye[30].

The number of MMOs required varies with jurisdiction, but generally there is a need to ensure that there are adequate numbers of personnel to facilitate visual observation during all daylight hours, factoring in relevant meal and comfort breaks. As detailed within Table 1, this can include having two observers on duty at any one time, such as offshore Greenland, Israel, Brazil and the USA. The USA mandates that observers can only be on duty for 4 hours before then taking a 2-hour break. In the UK, advice on the number of personnel is provided within a survey consent, and can vary depending upon area, time of year and other survey specificities. For example, surveys at high latitudes (north of 57° latitude) in the summer months (April 1st to October 1st) are likely to require more personnel due to the length of daylight hours (JNCC, 2017). While under certain circumstances an MMO may be a crew member, for example during some small-scale operations such as Vertical Seismic Profile (VSP) operations conducted at well locations typically using a small cluster of two to three compressed air sources deployed from the production platform or adjacent vessel, it is more commonplace that they be dedicated to their role and be an independent subcontractor of the survey licensee (JNCC, 2017).

Significant data are captured during visual observation (and concurrent acoustic monitoring) and recorded using sets of forms that are similar across jurisdictions, intended to record three sets of information: sightings, observer effort and details of the survey operation. Familiarisation with the data requirements is a key part of the training courses, in order to ensure that observers capture data accurately. The data forms are generally available as printable forms for completion while working on

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[29] Marine Mammal Observer Training Course Providers: https://jncc.gov.uk/our-work/marine-mammal-observer-training/

[30] Guide to making a rangefinder stick: https://data.jncc.gov.uk/data/e2a46de5-43d4-43f0-b296-c62134397ce4/Guide-making-rangefinder-stick-rev01-Web.xls

deck[31], as well as in spreadsheets[32] for data transcription, collation and ease of database entry when submitted to the relevant authority. An SML JIP funded review of data collection and potential use was undertaken by Barton et al. (2008) from which standardised forms were recommended for use globally, based upon those developed and issued by the JNCC. These have become the accepted standard for use in the UK, and are widely used elsewhere, though standardisation is still lacking due to regional specificities in mitigation protocols and consequent data requirements. Additionally, the JNCC provides a comprehensive guide to form completion[33].

Human error in data recording and in data transcription can reduce the utility of data for subsequent analyses such as those carried out periodically by agencies such as the JNCC (e.g. Stone et al., 2017). While the spreadsheet version of forms aims to improve data validation, there are also a variety of software programs commercially available that are either specifically aimed at marine mammal observation, or include modules for MMO data recording, with automated summary reporting, mapping and other functions[34,35].

## Passive Acoustic Monitoring

### PAM Operators

As with visual monitoring, acoustic monitoring requires specialised personnel to install and operate the relevant equipment. Passive Acoustic Monitoring (PAM) Operators are generally personnel that have undergone MMO training, followed by specialist PAM training in order to understand more about bioacoustics, acoustics and the acoustic monitoring technology. Training has lagged behind that of visual monitoring but is now much more prevalent, helping to raise standards among operators[29]. Industry has provided guidance relating to the use of PAM during operations[36]JNCC has also provided additional guidance relating to the practical issues associated with the use of PAM as a mitigation tool[10].

### Hardware

#### *Towed arrays*

PAM systems are a combination of hardware and software to detect, localise, track and classify vocalising marine mammals. The in-water equipment typically consists of a tow-cable in the region of 250m in length, fitted with a small number (typically 2-6) of either broadband hydrophones, or paired low to medium and high frequency hydrophones, which provide the capability to detect acoustic signals across a bandwidth of approximately 10-150,000 Hz. Groups of hydrophones are spaced in order to provide bearing information from the towed array to vocalising marine mammals. Towed arrays usually incorporate a depth sensor, through which the operator monitors deployment depth. The towed array cable is coupled to a signal processing and power supply unit, and the user interface by a deck cable (see Figure 6 below).

[31] Deck forms for geophysical surveys: https://data.jncc.gov.uk/data/e2a46de5-43d4-43f0-b296-c62134397ce4/Deckforms-rev04.doc
[32] Marine mammal recording form: https://data.jncc.gov.uk/data/e2a46de5-43d4-43f0-b296-c62134397ce4/Marine-mammal-recordingforms-rev04.xls
[33] Guide to using marine mammal recording forms: https://data.jncc.gov.uk/data/e2a46de5-43d4-43f0-b296-c62134397ce4/Marine-mammal-recordingforms-guide-rev05.pdf
[34] MMO/MFO/PSO in CheckPoint: https://www.midpointgeo.com/mmo-pso
[35] Mysticetus: https://mysticetus.com/
[36] IAGC Guidance on the Use of Towed Passive Acoustic Monitoring during Geophysical Operations. https://energeoalliance.org/wp-content/uploads/2019/06/iagc_pamguide_finalwithlinks.pdf

*Figure 7; typical PAM system comprised of user interface, signal processing unit, deck cable and towed array of hydrophones. Courtesy of Seiche Ltd.*

The deployment configuration of towed arrays can vary from vessel to vessel and can present challenges due to the amount of other in-sea equipment being towed behind an operational seismic survey vessel. The ratio of signal to noise can also present challenges due to the sounds produced both by the seismic source, from mechanical vibration through the vessel hull and cavitation of the propeller of the vessel, and from water flow across the surface of the hydrophone (flow noise), all of which can effectively limit the detection capabilities of PAM systems, particularly at low frequencies where these sounds dominate and limit the reliability of the system with respect to those species using LF to communicate (i.e. baleen whales and seals).

### *Vertically-deployed arrays*

PAM for seismic surveys carried out at exploration drilling rigs (borehole seismic, VSP) is generally carried out using hydrophone cables that are lowered vertically from the drilling platform or a stationary vessel, rather than as a towed array. Vertically deployed PAM (VPAM) or dipped hydrophone systems often include a single broadband hydrophone only, with wideband sensitivity that spans the frequency ranges of low-frequency marine mammal vocalisations and high-frequency echolocation clicks. The electronic processing units and user interface include the same functionality as towed array systems.

### *Integrated systems*

To overcome some of the limitations of towed, ancillary arrays, some seismic equipment manufacturers have developed systems integrated with the existing in-sea seismic equipment and navigation systems, for example, QuietSea[37] (Guerineau, 2014). This reduces the deployment

[37] QuietSea. https://www.sercel.com/en/products/passive-acoustic-monitoring-pam/quietsea

challenges and increases detection and localization capabilities due to the larger hydrophone spread being used for signal detection, as well as being combined with increased automation for signal classification (Guilment et al., 2018). Integration with navigation systems provides all stakeholders on the vessel awareness of detections as they occur. As with source technologies, integrated systems can require large capital expenditure to upgrade existing equipment and are not compatible with all seismic equipment spreads, meaning their use is less common than that of ancillary array systems.

Developments by other PAM equipment providers include a detachable 20m array cable that integrates onto the umbilical lines connecting the seismic source. This has an advantage over long towed array cables for ease of deployment, and locates the hydrophone array at the centre of the mitigation zone. In some circumstances however, PAM can be hampered by electrical interference associated with existing power and signal lines within the shared source umbilical (Pierpoint, pers. comm).

## Software

Initially more of a research tool, PAM relied upon a number of software interfaces, with that used most commonly developed by the International Fund for Animal Welfare (IFAW)[38]. As functional requirements increased to facilitate the use of PAM as a reliable mitigation tool, industry, through the SML JIP funded the development of a dedicated software system to enhance the detection, classification and localisation capabilities, as well as put in place relevant support and training. Since its introduction, PamGuard[39] has become the standard interface for the majority of PAM systems based on the use of towed ancillary arrays (Gillespie & Mallows, 2008; Mackey et al., 2009).

## Remote PAM

Remote PAM allows for the monitoring of PAM systems by teams of personnel based onshore anywhere in the world, using satellite connectivity to transfer data in real-time (Johnston & Wyatt, 2015). The potential benefits of such systems include secondary expert review of data in real-time, access by multiple users including client and potentially regulatory personnel, as well as the potential to reduce the number of personnel offshore, resulting in reduced health and safety risk (Johnston & Wyatt, 2015). RPAM has been implemented successfully for several large-scale seismic surveys. Satellite 'up-time' in the order of up to 98% can be achieved, although it is dependent on the quality of the satellite link (Johnston & Wyatt, 2015). The increased bandwidth of modern satellite communications systems such as Starlink[40] mean that this is a rapidly moving development.

Remote PAM systems have also implemented wireless technologies to monitor hydrophones deployed from anchored buoys during seismic surveys. For example, radio telemetry buoys were deployed during a 4D survey in Sakhalin, Russia, to monitor western grey whale activity within a known foraging area, with further analyses undertaken to estimate geospatial sound exposure (Bröker et al., 2015; Racca et al., 2023). The use of remote telemetry devices for real-time acoustic monitoring and mitigation is increasing as cost-effective access to satellite and GSM systems has become more widely

[38] IFAW software. http://www.marineconservationresearch.co.uk/downloads/logger-2000-rainbowclick-software-downloads/
[39] Pamguard software. https://www.pamguard.org/
[40] Starlink: https://www.starlink.com/

available. This is also an area where there is crossover of technologies currently in use to monitor marine mammals in high traffic areas or during offshore pile-driving activities for offshore wind.

## Acquisition Delays and Shutdowns

If marine mammals or other protected species are identified as being within the source exclusion zone, two actions are advisable, depending on the jurisdiction within which an operation is taking place. Prior to the start of acquisition, the initiation of the sound source can be delayed until the protected species has been absent from the exclusion for a defined period of time. For example, in the UK the soft-start can commence after 20 minutes since the last sighting (JNCC, 2017). Neither the UK nor Ireland require the source to be deactivated once it is active due to the presence of protected species, however, it is common in most other jurisdictions, and in the USA, for example, the source must be immediately deactivated due to the presence of marine mammals (with some exceptions), with resumption of operations allowed only following a further pre-acquisition observation period and soft-start procedure (BOEM, 2020). Deactivation of the sound source and therefore stoppage of data acquisition for any period of time, means that the data needs to be acquired at another time. Typically, a vessel will circle with the source inactive for a period in order to turn and return to the gap in the survey acquisition and resume operations to fill the gap, as depicted in Figure 7. This can extend the duration of surveys, resulting in additional exposure to risks for the crew and sound and emissions in the environment.

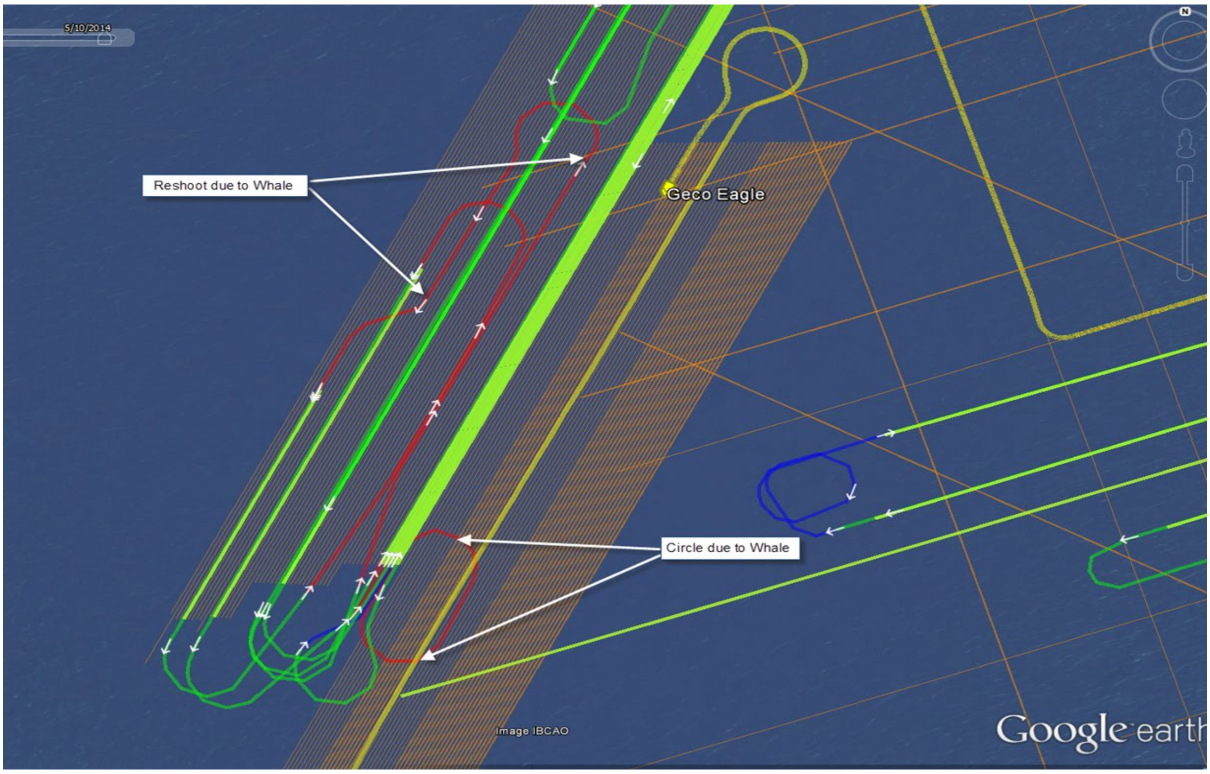


*Figure 8; illustration of infill required due to sound source being deactivated due to the presence of marine mammals (image courtesy of Peter Seidel, PGS)*

## Developing Monitoring Methods

### Visual Augmentation and Low Visibility

There are a variety of methods that can be employed to augment visual observations in daylight conditions (such as high-definition camera technology), as well as tools more specifically designed to enhance observational capacity during low visibility, including night-vision, infra-red (IR) thermal imaging, radio-detection and ranging (RADAR) and active acoustic monitoring (AAM) (Verfuss et al., 2018). While not all of these methods are widely used and in many cases are the subject of ongoing research, development and efficacy testing, some have become commonplace in certain segments of the offshore industry. Within the northeast USA, survey contractors undertaking HRG surveys have teams of PSOs onboard to monitor for protected species, and especially the North Atlantic right whale (NARW). PSOs may use handheld night-vision binoculars and thermal clip-on devices or other thermal systems, while there are additional requirements for ASVs, for example HD/thermal camera systems have been used to provide real-time images for PSOs to monitor from a mother vessel. The use of these systems is the subject of review on a project-by-project basis by the relevant competent authority.

While the range of developing techniques is described briefly here, detailed reviews have been prepared by Verfuss et al. (2016; 2018) under the E&P Sound and Marine Life Programme, which provide excellent detail of the pros and cons of each method as well as information about the companies working on these developments and, in some cases, commercial offerings.

### High-definition cameras

High-definition (HD) camera systems have been tested and used commercially on geophysical surveys in locations including South Africa, Sakhalin (Russian Federation) and the USA (Seiche Ltd, 2020). They are capable of providing a 360-degree view of the sea surface, with additional software applications able to aid observers in calculating the distance of protected species relative to mitigation zones around the sound source (Seiche Ltd, 2020).

As described, the use of high-definition (HD) camera technology has expanded in part due to the developments of autonomous survey platforms which separate the source from monitoring personnel, as well as potential applications for offshore construction and other activities subject to similar mitigation protocols for underwater noise input.

### Night-vision and thermal infra-red

Often paired with HD camera technology, night vision and thermal IR technology is an area of more dedicated research and development in order to overcome the limitations of visual observations during periods of low visibility, and as a tool to further augment acoustic monitoring techniques. While night vision enhances ambient light in the visible or near-visible spectrum, detection with thermal IR requires a temperature difference between the target and the environment, with the surfacing body of a cetacean or their blows being identifiable cues (Smith et al., 2020). While handheld binocular systems are in broad use in some areas, with limited evaluation of their efficacy, larger camera systems for installation on vessels (see below) are receiving more attention, with a variety of systems available, often adapted from other uses such as search and rescue or defence. These have health and safety benefits for observer teams in terms of being able to monitor screens within the vessel, rather than working on deck (Seiche Ltd, 2020).

*Figure 9; HD and thermal camera system installed on a vessel. Courtesy of Jan De Nul and Seiche Ltd.*

Results from the concurrent monitoring by visual observers and the Automated Infrared-based Marine Mammal Mitigation System (AIMMMS) IR camera system developed by *Rheinmetall Defence*[41] have shown that high detection rates can be achieved, detecting approximately twice as many cues as visual observers in some cases, and with capabilities for the automated detection of both large cetaceans and small delphinids (Smith et al., 2020; Zitterbart et al., 2013). However, the need for observer verification is also apparent, both in terms of identification of detected animals to species level, and due to the large number of false positive detections (84.5%), often caused by birds (Smith et al., 2020). The range of detection varies with platform height and environmental factors, with minimum and maximum distances ranging from 90m (due to obstructions on the vessel) to between 2 and 10km, depending on the size of the cetacean and environmental conditions, though distance estimates have not been provided for all trials (Seiche Ltd, 2020; Smith et al., 2020; Verfuss et al., 2018; Zitterbart et al., 2013).

Systems are negatively affected by environmental conditions including fog, precipitation, glare, and sea state, though capabilities at night benefit from the lack of glare in particular (Verfuss et al., 2018; Zitterbart et al., 2013). Recent work with the AIMMMS system also highlighted that small vessel platforms present problems due to the pitch and roll exceeding the extent to which the gimbal can stabilize the camera system, though on large commercial seismic vessels this should be less of a problem (Smith et al., 2020). In addition to effective stabilisation, detection performance is influenced by whether the sensor system is cooled or uncooled, with cooled systems having greater performance capabilities. Other systems being trialled and/or offered to the market include those from Currentcorp[42], Seiche[43], Teledyne-FLIR[44] and Toyon[45].

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[41] AIMMMS: https://www.rheinmetall-defence.com/en/rheinmetall_defence/systems_and_products/c4i_systems/reconnaissance_and_sensor_systems/automatic_marine_mammal_mitigation/index.php
[42] https://www.currentcorp.com/offshore-deep-sea-commercial
[43] https://www.seiche.com/underwater-acoustic-products/specialist-systems/thermal-imaging-hd-camera/
[44] https://www.flir.co.uk/browse/marine/fixed-mount-thermal-cameras/
[45] https://www.toyon.com/toyon-supports-noaa-gray-whale-research-with-maritime-infrared-camera-technology/

The HD cameras and combination IR systems have been highlighted as being a complimentary tool to the use of MMOs and PAM, serving as a warning system to assist rather than replace personnel (Zitterbart et al., 2013). The combination of techniques enables greater detection capabilities for marine mammals, noting that each method has drawbacks which limit their utility in isolation (Verfuss et al., 2018). The development and refinement of Artificial Intelligence (AI) also is also being explored to enhance the automation of detection of marine mammals from the video feed (Jan De Nul, 2022).

### RADAR

Radio detection and ranging (RADAR) relies upon the detection of reflected electromagnetic waves by a target. Early work by DeProspo et al. (2005) as part of the Cetacean Detection and Radar (CEDAR) project demonstrated that large baleen whales (fin whales) and small delphinids (*Stenella* sp.) could be detected and tracked at a range of ca. 5.5km during ship-based trials in low sea states (< Beaufort 3). Recent work has looked at the capability of shore-based X-band radar systems to detect cetaceans including bottlenose dolphins in the Mediterranean (Mingozzi et al., 2020) and killer whales at the European Marine Energy Centre offshore Orkney (McCann & Bell, 2017). While strong echoes from the marine mammal targets were noted, which could be differentiated from targets such as sailing vessels, observer verification is necessary (Mingozzi et al., 2020). While RADAR units have notable potential benefits in terms of 360-degree capability and being less affected by environmental factors such as fog and precipitation, they remain limited by sea state, and at present there is a lack of empirical data about the performance of commercial systems as a practical mitigation tool at this time (Verfuss et al., 2018).

### Active Acoustic Monitoring

A major drawback with PAM is the inability to detect silent animals, or those that may be vocalising but remain undetected by the system due to the ambient noise environment or lack of relevant capability in a given frequency band. Active Acoustic Monitoring (AAM) therefore represents an alternative method that has greater ability to fully detect, localise, track and classify marine mammal and other species (Stein, 2011). AAM is based on the use of sound being emitted to detect reflections back from marine species, with the potential utility of systems the subject of studies from both vessels and in relation to stationery marine renewable devices (Hastie, 2013; Pyć et al., 2016). In terms of practicality, AAM systems detection performance is influenced by a trade-off between range and resolution, whereby small species in particular require relatively high-frequency sonar which reduces the effective detection range (Verfuss et al., 2018), while the detection of larger species at ranges practical for mitigation (up to ~2km) was demonstrated by Pyć et al. (2016). A notable disadvantage is the issue of the additional sound being introduced to the marine environment, which is counter-intuitive to the purpose of the mitigation and something to be considered in terms of the overall risk of a given operation and potential benefit from using AAM (Verfuss et al., 2018).

## 6. Post Survey Phase

### Reporting

Following the completion of a survey, there is a common requirement for the licence holder to ensure that a report is compiled to summarise the data collected by the onboard MMO and PAM team which also highlights any compliance issues relating to the implementation of the relevant mitigation measures. Those reports are provided to the relevant competent authority, who may periodically analyse the data.

### Data Sharing and Analysis

Both the JNCC in the UK and BOEM in the USA have undertaken periodic analyses of MMO/PSO data collected during the course of geophysical operations within those jurisdictions (Barkaszi et al., 2012; Stone et al., 2017; Stone & Tasker, 2006). A sparse, but more global dataset was the subject of an industry funded research project published in 2019 (Milne et al., 2019). There is no single repository of visual observer data, or passive acoustic monitoring data, with such data being compiled by the relevant regulatory agency in a given jurisdiction where such exists, though the potential merits of a repository have been discussed by (Barton et al., 2008; Milne et al., 2019). Some data from geophysical survey operations has been voluntarily reported into global data repositories including the Ocean Biodiversity Information System for the Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP)[46], which collates a variety of opportunistic and dedicated survey data within a publicly accessible online database. In the U.S. Gulf of Mexico, EnerGeo Alliance launched a program in April 2021 intended to meet requirements for reporting of marine mammal detection data collected under National Marine Fisheries Service (NMFS) requirements for the region. The Gulf of Mexico Proactive Regulatory and Observational Program (GOM-PROP)[47] hosts marine mammal visual and acoustic detections for the majority of geophysical operators in the region. A similar database called NETUNO[48] is operational for activities offshore Brazil, providing the regulator, project proponents and other stakeholders with transparent information regarding marine mammal sightings, detections and mitigation measures. As these programmes continue, the long-term datasets produced will provide invaluable insight.

In the case of the European Union (EU), the Marine Strategy Framework Directive (MSFD) requires that impulsive noise data whether from seismic surveys, or other sources such as construction piling must be reported to each national competent authority. Those data are, in turn collated by OSPAR within the Impulsive Noise Registry administered by the International Council for the Exploration of the Seas (ICES)[49]. Both prior to leaving the EU and since, the UK has collated such data within the Marine Noise Registry, administered by the JNCC[50], to which post-activity reports are submitted in order to understand where and when sources operating in the frequency range between 10Hz – 10kHz have been active. The collated data for the OSPAR region is available within the Impulsive Noise Registry. Those data are summarised by 'pulse block day' (the number of days per ICES area block within which an impulsive source has been active) and forms the basis of further work by OSPAR to assess and understand the potential for cumulative impacts impulsive noise within the OSPAR area (e.g. (Merchant et al., 2022).

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