

The logo for MARA (Maritime Area Regulatory Authority) features the word "MARA" in a bold, blue, sans-serif font. The letters are slightly shadowed, giving them a three-dimensional appearance as if they are floating above the background. The background is a photograph of a sunset over the ocean, with a bright sun low on the horizon and its light reflecting on the water's surface. On the left side of the cover, there are several overlapping, curved bands in shades of teal and light blue, creating a dynamic, wave-like graphic element.

An tÚdarás Rialála Limistéir Mhuiri  
Maritime Area Regulatory Authority

# REVIEW OF IMPACTS OF GEOPHYSICAL AND GEOTECHNICAL SURVEYS ON MARINE FISH AND SHELLFISH IN IRISH WATERS

This report has been prepared by:

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Maritime Area Regulatory Authority (MARA)

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This report serves as a record of work commissioned by MARA. However, the views and recommendations presented in this report are not necessarily those of MARA and should, therefore, not be attributed to MARA.

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Review of Impacts of Geophysical and Geotechnical surveys on marine fish and shellfish in Irish waters

## Table of Contents

1.	Introduction	8
1.1.	Purpose of this report	8
1.2.	Legislative and Regulatory Context	9
2.	Site Investigation Surveys	11
2.1.	Geophysical Surveys	11
2.1.1.	Multibeam Echosounder (MBES)	11
2.1.2.	Side-Scan Sonar (SSS)	12
2.1.3.	Sub-Bottom Profiling (SBP)	12
2.1.4.	Air guns	12
2.1.5.	Magnetometer	12
2.1.6.	Ultra-Short Baseline (USBL)	13
2.2.	Geotechnical Surveys	13
2.2.1.	Cone Penetrative Testing (CPT)	13
2.2.2.	Cable percussion borehole	14
2.2.3.	Rotary corehole	14
2.2.4.	Vibrocore	14
2.2.5.	Vane Shear Test (VST)	14
2.2.6.	Dynamic Probe (Heavy) (DPH)	15
2.2.7.	Sediment Grabs	15
2.2.8.	Gravity corer	15
3.	Key fish and shellfish species within scope	16
4.	Key impacts of site investigation surveys on fish and shellfish	19
4.1.	Impacts from Underwater Noise	19
4.1.1.	Impulsive Noise	21
4.1.2.	Continuous Noise	24
4.1.3.	Discussion on the impacts of Underwater Noise on fish and shellfish	26
4.2.	Impacts from physical disturbance (other than noise)	28
4.2.1.	Habitat loss or removal	28
4.2.2.	Suspended Sediments or smothering	30
4.2.3.	Habitat complexity vs sensitivity to physical disturbance	32
4.3.	Cumulative Impacts	34
5.	International Best Practice	36
5.1.	Common Conditions relevant to an Irish context	37
5.2.	Staged approach to assessing SI survey impacts	38
6.	Key knowledge gaps identified	40
7.	Recommendations	42
8.	References	47
9.	Appendices	52

9.1.	Appendix I	52
9.1.1.	Systematic Literature Review methodology	52
9.1.2.	Search terms used for identifying international best practice documents	52
9.2.	Appendix II	53

## Table of Figures

Figure 2.1 Conceptual diagram of common Geophysical survey methods (credit: AL).....	11
Figure 4.1 Benthic broad habitat types in Irish waters, from the Biodiversity theme of Ireland’s Marine Atlas (accessed <a href="http://atlas.marine.ie/">http://atlas.marine.ie/</a> 03/02/2026). .....	33
Figure 7.1 Spawning Grounds for select fish species in Irish waters. Data from the Fish Species Distribution theme accessed through Ireland’s Marine Atlas at <a href="http://atlas.marine.ie/">http://atlas.marine.ie/</a> , 03/02/2026. ....	44
Figure 7.2 Nursery Grounds for select fish species (green) and <i>Nephrops</i> grounds in Irish waters. Data from the Fish Species Distribution theme accessed through Ireland’s Marine Atlas at <a href="http://atlas.marine.ie/">http://atlas.marine.ie/</a> , 03/02/2026.....	45

## List of Tables

Table 3.1. List of key fish and shellfish species within the scope of this study. ....	16
Table 4.1. Anatomical groupings of the key species in Irish waters within the scope of this study, based on categories from Popper <i>et al.</i> (2014).....	20
Table 5.1 Examples of UK MMO site investigation licence conditions relevant to fish and shellfish receptors.....	37
Table 7.1: Spawning periods and peak spawning periods for selected species adapted from Coull <i>et al.</i> , 1998, and Ellis <i>et al.</i> , 2012. Light blue = spawning periods; dark blue = peak spawning. ....	43
Table 7.2 Seasonal presence of key Irish diadromous species between freshwater, estuarine and marine water. M = marine, F = freshwater, MF = freshwater or marine, E = estuarine. EF = estuarine or freshwater (O’leary, Brett & Poole, 2022).....	43
Table 9.1. A summary of impulsive noise studies used within the Impacts from Underwater Noise section (4.1.1). SPL refers to sound pressure level, SEL refers to sound exposure level and SVL refers to sound velocity level. Grouping refers to anatomical grouping based on Popper <i>et al.</i> (2014).....	52
Table 9.2. A summary of continuous noise studies used within the Impacts from Underwater Noise section (4.1.2). SPL refers to sound pressure level, SEL refers to sound exposure level and SVL refers to sound velocity level. Grouping refers to anatomical grouping based on Popper <i>et al.</i> (2014).....	55

## List of Acronyms and Units

Abbreviation	Definition
AA	Appropriate Assessment
ASA	Acoustical Society of America
BACI	Before–After Control–Impact
BOEM	Bureau of Ocean Energy Management
BSH	Federal Maritime and Hydrographic Agency
CEMP	Construction Environmental Management Plan
CFR	Code of Federal Regulations
CPT	Cone Penetration Test
CPTu	Cone Penetration Test with pore water pressure measurement
DDV	Drop-Down Video
DPH	Dynamic Probe (Heavy)
DCCEEW	Department of Climate Change, Energy, the Environment and Water
EFH	Essential Fish Habitat
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EN	Endangered
EU	European Union
FLO	Fisheries Liaison Officer
GES	Good Environmental Status
INFOMAR	Integrated Mapping for the Sustainable Development of Ireland’s Marine Resource
ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering
JNCC	Joint Nature Conservation Committee
MAP Act	Maritime Area Planning Act 2021
MARA	Maritime Area Regulatory Authority
MARPOL	International Convention for the Prevention of Pollution from Ships
MBES	Multibeam Echosounder
MMO	Marine Management Organisation
MSA	Magnuson–Stevens Fisheries Conservation and Management Act
MSFD	Marine Strategy Framework Directive
MUL	Maritime Usage Licence

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<b>Abbreviation</b>	<b>Definition</b>
NIS	Natura Impact Statement
NMFS	National Marine Fisheries Service
NMPF	National Marine Planning Framework
NOAA	National Oceanic and Atmospheric Administration
ORE	Offshore Renewable Energy
OSPAR	Oslo–Paris Convention
ROV	Remotely Operated Vehicle
SBP	Sub-Bottom Profiler
SSS	Side-Scan Sonar
TC1	Technical Committee 1
UK	United Kingdom
UXO	Unexploded Ordnance
VST	Vane Shear Test

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## Executive Summary

This report summarises the current scientific understanding of how marine geophysical and geotechnical site investigation surveys impact fish and shellfish in Irish waters. It is intended to support evidence-led decisions for preparing and assessing Maritime Usage Licence applications.

### **Key impact pathways**

Underwater noise and physical disturbance of the seabed are the main potential impact pathways. Most survey activities have a small spatial footprint, and effects are typically localised and short term, particularly for mobile adult fish and shellfish. Impacts are more likely where surveys overlap with sensitive habitats, vulnerable life stages, or occur repeatedly in the same area.

### **Noise-related effects**

The evidence base is strongest for underwater noise. Behavioural responses are the most consistently observed effect, including startle responses, short-term displacement and altered foraging or schooling behaviour. For eggs, larvae and some shellfish, intense impulsive noise can cause injury or mortality under certain conditions. Continuous noise is more often linked to stress responses and behavioural disruption, particularly where exposure is prolonged.

### **Physical disturbance of the seabed**

To our knowledge, there have been no studies on the physical impacts of geotechnical surveys on fish or shellfish. Potential effects are inferred from studies on dredging, drilling, aggregate extraction and bottom fishing. Seabed disturbance can cause localised benthic mortality, alter habitat structure and reduce prey availability. While geotechnical survey footprints are highly localised, significant impacts are most likely near sensitive habitats or during key fish spawning periods and spawning areas which are species specific.

### **Cumulative effects**

Cumulative risk increases where surveys are clustered, repeated over time, or overlap with other marine activities. Species responses are likely driven by a combination of noise, vibration, physical presence and sediment disturbance rather than any single pressure acting alone. This is poorly documented in the literature and requires further research attention.

### **Knowledge gaps**

Key knowledge gaps include the lack of field studies on geotechnical survey impacts on fish and shellfish, limited data on behavioural and sub-lethal effects for many species, uncertainty around early life stage sensitivity, and a lack of international best practice for managing impacts of site investigation surveys on fish and shellfish (or associated habitats).

### **Recommendations**

Mitigation should be proportionate and precautionary where uncertainty remains. Key measures include avoiding sensitive habitats and life stages such as spawning periods, minimising repeated disturbance through coordinated planning, selecting lower-impact methods where feasible, managing noise and sediment disturbance, and ensuring robust survey planning, data sharing and communication with stakeholders.

# 1. Introduction

Ireland's maritime area is undergoing a period of significant change, driven by major reforms in marine policy, legislation, and governance, alongside increasing levels of activity and demand for marine space. The introduction of the Maritime Area Planning Act 2021 has fundamentally restructured the management and regulation of maritime activities, placing greater emphasis on integrated marine planning, environmental protection, and evidence-based decision making.

The establishment of the Maritime Area Regulatory Authority (MARA) in 2023 as Ireland's primary marine regulator has increased the need for clear, consistent, and accessible information to support both regulatory assessment and project planning. Site investigation surveys are a key component of marine development, yet they can impact marine environments in many ways. For some species such as fish and shellfish, our understanding of these impacts is fragmented in both space and time. There is a need for a consolidated synthesis of current scientific understanding to inform proportionate planning and assessment in the context of the Maritime Usage Licence process.

## 1.1. Purpose of this report

This report provides a synthesis of the potential impacts of marine geotechnical and geophysical site investigation surveys on fish and shellfish in Irish waters, with specific relevance to the Maritime Area Planning Act 2021 (MAP Act). It is intended to function as a practical guidance document for the Maritime Area Regulatory Authority (MARA), applicants and other stakeholders involved in the assessment and planning of Maritime Usage Licence (MUL) applications for marine site investigation surveys. In particular, the report is designed to:

- support evidence-based decision making for site investigation surveys with regard to fish and shellfish that may be sensitive to the potential impacts of such surveys in Irish waters;
- improve understanding of the nature and impact pathways associated with different geophysical and geotechnical site investigation survey methods;
- identify where the scientific evidence base is relatively robust and where it remains limited;
- highlight key knowledge gaps that may warrant a precautionary approach and help inform future research priorities; and
- provide an overview of international best practice and recommendations for mitigation and management measures, so that applicants can make informed decisions when designing survey programmes, proposing mitigation, and addressing uncertainty within MUL applications.

It should be emphasised that this report does not replace the requirement for site-specific environmental assessments where these are required under the MAP Act or other applicable national or European legislation. Rather, it provides a synthesis of the current scientific understanding of the impacts of site investigation surveys on fish and shellfish, drawing on peer-reviewed literature, grey literature and international guidance. The report reflects the state of knowledge as of 2025 and should therefore be interpreted as a snapshot of current understanding at this time. As highlighted

throughout, significant knowledge gaps remain, and understanding of potential impacts is likely to evolve as new evidence emerges.

## 1.2. Legislative and Regulatory Context

The Maritime Area Planning Act 2021 establishes the legislative basis for the regulation, management, and sustainable use of Ireland's maritime area (Maritime Area Planning Act 2021). Under the Act, certain activities listed in Schedule 7 require a Maritime Usage Licence issued by the Maritime Area Regulatory Authority (MARA) (Maritime Area Planning Act 2021, Sch. 7). These activities include marine environmental surveys undertaken for the purposes of site investigation, or in support of an application under Part XXI of the Planning and Development Act 2000, as listed in Schedule 7, paragraph 3 of the Maritime Area Planning Act 2021. Geotechnical and geophysical site investigation surveys fall within this category and are therefore subject to assessment and determination by MARA through the Maritime Usage Licence process.

In determining an application for a Maritime Usage Licence, MARA must consider a range of national and European policy instruments and statutory obligations. These include the National Marine Planning Framework (National Marine Planning Framework, 2021), which provides the overarching spatial planning framework for marine activities and seeks to balance sustainable development with the protection of the marine environment.

MARA must also have regard to the State's obligations under several European Union Directives, insofar as they are relevant to the proposed maritime usage. These include the Habitats Directive (Council Directive 92/43/EC) and the Birds Directive (Directive 2009/147/EC), which together form the basis of the Natura 2000 network and require the protection of designated habitats and species, as well as the strict protection of Annex II and Annex IV species. Many fish, shellfish, elasmobranchs, lampreys, eels, and marine mammals are afforded protection under these Directives. Potential impacts from underwater noise, seabed disturbance, and other pressures associated with site investigation surveys may therefore be relevant to screening for Appropriate Assessment (AA) and in the consideration of risk to protected species.

The Water Framework Directive (2000/60/EC) is also relevant where site investigation surveys have the potential to affect coastal or transitional water bodies. Under this Directive, Ireland is required to prevent deterioration in the status of water bodies and to protect designated objectives. Disturbance of sediments, mobilisation of contaminants, or other physical pressures associated with geotechnical surveys may be relevant considerations in this context. The former Shellfish Waters Directive has been subsumed into the Water Framework Directive, and shellfish waters and associated ecological objectives are therefore considered through that framework where relevant.

MARA must also have regard to the State's obligations under the Marine Strategy Framework Directive (MSFD), which aims to achieve or maintain Good Environmental Status (GES) of the marine environment. The MSFD includes descriptors that are directly relevant to site investigation surveys, including underwater noise, seabed integrity, biodiversity, and populations of commercially exploited fish and shellfish. Although the evidence base for the status of some of these descriptors remains limited, MARA is required to consider whether proposed activities could affect the achievement or

maintenance of GES across all relevant MSFD descriptors, including in the context of other marine users such as fisheries and aquaculture (DHLGH, 2024).

The MAP Act also requires MARA to take account of other lawful maritime uses in the same area, as well as broader national policy commitments, including those relating to biodiversity protection and sustainable use of marine resources. This includes consideration of commercially important fish and shellfish stocks, species of high conservation concern, and the cumulative effects of multiple activities over time.

Within this regulatory context, this report aims to support MARA's role by synthesising the current scientific evidence on the impacts of geotechnical and geophysical site investigation surveys on fish and shellfish in Irish waters. It serves as a guidance document to assist in understanding how these impacts relate to statutory obligations under the MAP Act and associated European Directives, and where uncertainty or data gaps may need to be addressed through environmental monitoring, mitigation measures, or future research when assessing applications for Maritime Usage Licences.

### Key messages

- Marine site investigation surveys in Ireland require a Maritime Usage Licence under the Maritime Area Planning Act 2021. MARA is Ireland's primary maritime regulator as of 2023.
- This report reviews impacts of marine site investigation surveys on fish and shellfish.
- The report is intended to support proportionate, evidence-based Maritime Usage Licence assessments and applications by MARA, applicants and other stakeholders.

## 2. Site Investigation Surveys

Site investigation surveys are a fundamental component of the planning and design of marine and coastal developments, providing essential information to support site selection and engineering decision making. They are undertaken to characterise seabed and sub seabed conditions, identify geological constraints and hazards, and reduce uncertainty and risk prior to construction. Such surveys support a wide range of projects, including, but not exclusively, effluent discharge pipes, ports and harbours, quays and piers, subsea cables and pipelines, offshore renewable energy infrastructure, and oil and gas installations. The sections that follow describe the main geophysical and geotechnical survey methods used to inform these activities.

### 2.1. Geophysical Surveys

The purpose of geophysical surveys is to characterise the seabed and sub-seabed through remote sensing techniques that map seafloor morphology, identify sediment types, and detect geological structures and potential hazards (McDowell, 2002). These remote sensing techniques include using acoustic and electromagnetic methods such as Multibeam Echosounders (MBES), Side-Scan Sonar (SSS), Sub-Bottom Profilers (SBP), and magnetometers, which collect continuous, high-resolution data of the seabed structure across the survey area (Figure 2.1). Geophysical investigations are therefore an essential component of most marine developments. Another core function of geophysical surveys is to inform the design of subsequent geotechnical surveys, environmental surveys and archaeological surveys that may be required. Brief descriptions of the most common geophysical survey methods are described below.

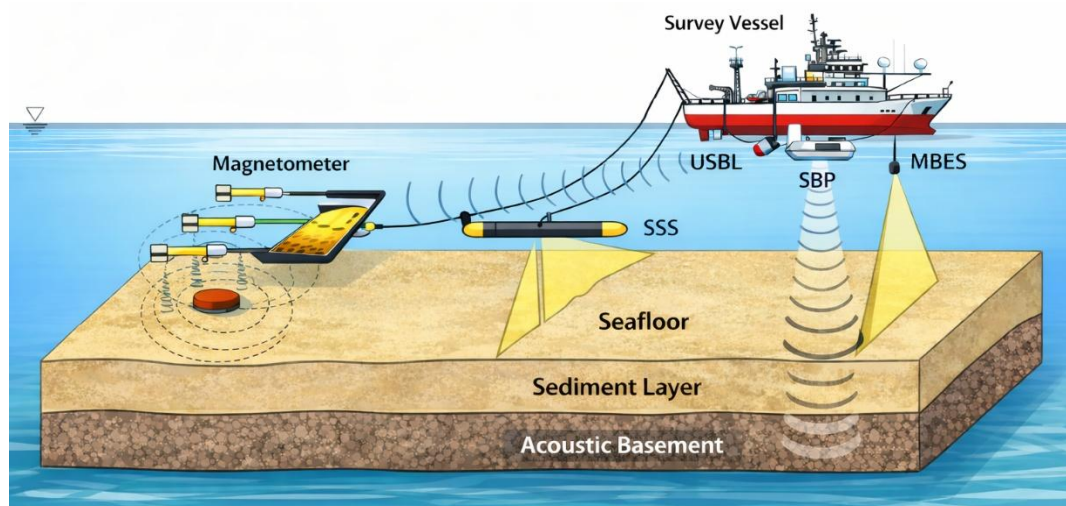


Figure 2.1 Conceptual diagram of common Geophysical survey methods (credit: AL).

#### 2.1.1. Multibeam Echosounder (MBES)

MBES systems map the seabed by emitting multiple acoustic beams across a wide swath beneath the survey vessel and measure the two-way travel time of the returned signals. This produces high-resolution bathymetric data that accurately defines seabed morphology, including slopes,

depressions, bedforms, and potential hazards (Figure 2.1). The resulting datasets provide essential inputs for engineering design, navigation risk assessment, cable and pipeline routing, and the planning of subsequent geophysical and geotechnical investigations. MBES surveys are typically conducted from surface vessels equipped with hull-mounted or pole-mounted transducers, allowing continuous, high-coverage mapping across the survey area (Radzevicius, 2014).

#### **2.1.2. Side-Scan Sonar (SSS)**

SSS characterises the seabed by transmitting acoustic pulses laterally from a towed or hull-mounted sonar unit and recording the intensity of the backscattered sound (Figure 2.1). This produces detailed imagery of seabed texture and features, enabling the identification of sediment types, boulders, debris, wrecks, scour, sand waves, and other morphological or anthropogenic objects. The acoustic signatures captured by SSS provide critical information for engineering design, UXO risk assessment, environmental baseline studies, and the safe placement of offshore infrastructure. SSS systems are commonly deployed as towed “fish” behind a survey vessel to maximise resolution and proximity to the seabed (McDowell, 2002).

#### **2.1.3. Sub-Bottom Profiling (SBP)**

SBP investigates the shallow sub-seabed by emitting low-frequency acoustic pulses that penetrate beneath the seabed surface and reflect off sedimentary layers and geological boundaries (Figure 2.1). The returned signals are processed to generate vertical profiles that reveal sediment thickness, stratigraphy, buried objects, and shallow geological hazards. These data provide essential context for geotechnical sampling, foundation design, cable burial assessment, and the identification of features such as peat layers, hardgrounds, or bedrock. SBP systems may include high-resolution chirp profilers for shallow penetration or boomer / sparker sources for deeper imaging and are typically deployed from surface vessels using hull-mounted or towed configurations (McDowell, 2002).

#### **2.1.4. Air guns**

Air guns are high-energy seismic acoustic sources used to investigate deep sub-seabed geology by releasing compressed air into the water column, generating powerful broadband pressure waves that penetrate hundreds to thousands of metres below the seabed. The returning reflections from geological boundaries are recorded by hydrophone streamers and processed to create seismic profiles that reveal large-scale stratigraphy, structural features, and basin architecture. Air-gun systems provide far greater penetration than engineering-scale geophysical tools such as chirp, boomer, or sparker sources, and are therefore used primarily for deep geological mapping and hydrocarbon exploration rather than routine offshore site investigations (McDowell, 2002).

#### **2.1.5. Magnetometer**

Magnetometer surveys detect variations in the Earth’s magnetic field to identify ferrous materials and magnetically distinct features beneath the seabed. By measuring subtle anomalies caused by buried metal objects, geological structures, or anthropogenic debris, magnetometers provide a detailed map of magnetic signatures across a survey area. These data are crucial for locating pipelines, cables, wrecks, anchors, and unexploded ordnance (UXO), as well as for supporting route planning and hazard

assessment for marine infrastructure. Magnetometers do not emit sound but rather measure magnetic fields (Radzevicius, 2014).

#### **2.1.6. Ultra-Short Baseline (USBL)**

Ultra-Short Baseline (USBL) positioning is an acoustic tracking technique widely used in marine geophysical surveys to determine the real-time underwater position of towed sensors and seabed equipment. The system operates by transmitting acoustic signals between a transceiver mounted on the survey vessel and a transponder attached to the subsea equipment, allowing precise range and bearing calculations.

## **2.2. Geotechnical Surveys**

Unlike geophysical surveys, which provide indirect and spatially continuous information on seabed morphology and stratigraphy, geotechnical investigations use intrusive methods to directly measure ground conditions at discrete locations and to define their variation with depth. Geotechnical investigations typically comprise a combination of drilling, sediment sampling, and in-situ testing (e.g. boreholes, vibrocores, and Cone Penetration Tests (CPTs)). Boreholes and vibrocores are primarily sampling methods while CPTs provide in-situ ground strength and stratigraphy data. These surveys are undertaken to define the geological, geotechnical, and mechanical properties of seabed materials with depth. Individual investigations have a limited lateral extent; however, when interpreted alongside geophysical survey data, they provide critical ground-truthing that enables the development of a robust and reliable ground model. Geophysical survey outputs are used to inform the design of the geotechnical campaign by identifying spatial variability, data gaps, and areas of uncertainty where intrusive investigation is required. The primary objective of the geotechnical survey is to provide the ground parameters necessary for detailed geotechnical assessment, including geological classification, material properties, strength, and in-situ soil/rock behaviour (Audibert & Huang, 2005). Some common geotechnical survey methods are explained below.

#### **2.2.1. Cone Penetrative Testing (CPT)**

CPT assesses the characteristics of the seabed sediments by pushing a rod-shaped instrument with a conical head (3-5 centimetres (cm)) into the seabed at a constant rate of penetration, while continuously measuring cone tip resistance, sleeve friction, and for CPTu, pore water pressure using drilling muds. The combined response of these three parameters produce a characteristic signature of the sediment, allowing the sediment type and the stratification to be interpreted, and providing direct input parameters for geotechnical design (e.g. strength, stiffness, relative density). Offshore CPTs can be carried out from a surface platform (such as a jack-up barge or floating vessel with a CPT rig), or from equipment deployed at the seabed. Penetration depths are typically shallow (5-10 m), but CPT can be deployed to depths of 50 – 70 metres (m) if required. There is no sample taken from the ground and, due to the small hole diameter, there is no backfilling of the hole required (Audibert & Huang, 2005).

### 2.2.2. Cable percussion borehole

A borehole is a method of vertical (or near-vertical) drilling into seabed to recover samples and perform in-situ tests on sediments and rock types at various depths. A drill string with rotary bit (typically 20 cm in diameter) advances the hole, typically using temporary casing to prevent collapse. Cuttings are then flushed out using seawater or drilling mud, while core barrels recover undisturbed samples. Offshore boreholes are typically performed from surface platforms such as vessels with dynamic positioning or jack-up barges. Penetration depths can be shallow (5 - 10 m) or deep (50 – 100 m) if required. The void left from the borehole is usually backfilled to seabed level with sodium bentonite pellets coated with a biodegradable non-sticking film that retards the hydration time. The pellets swell when submerged in water to form a low permeability seal to the hole (Audibert & Huang, 2005).

### 2.2.3. Rotary corehole

Rotary corehole drilling is used to determine the depth to rock and to obtain representative core samples of rock for lab testing. The drilling method involves a rotary cutting head (typically 10 cm diameter) on the end of a steel cylindrical core barrel, hydraulically pushed into the ground due to the abrasive grinding of the annulus (Audibert & Huang, 2005). Geotechnical investigations typically use drilling fluids (also called drilling muds or flushes) such as bentonite gel, a clay-based suspension that lubricates the drill bit, removes cuttings, stabilises the borehole walls, and prevents fluid loss into sediments. In some situations, seawater is used in less demanding conditions. Sodium bentonite (a swelling clay powder mixed into a slurry) is often used to backfill and seal holes after rock cores are retrieved, preventing collapse or contamination. Penetration depths can be shallow (5–10 m) or deep (50–100 m).

### 2.2.4. Vibrocore

Vibrocores recover cylindrical core samples of seabed sediment using high-frequency vibration or rotation, allowing a hollow cone barrel to penetrate with minimal disturbance. The core barrel is driven into the sediment until refusal (no further penetration) or reaching a predetermined depth, then carefully retrieved. Recovered cores provide detailed in-situ stratigraphic and geological information, from which sediment properties and mechanical characteristics can be determined via laboratory analysis. Penetration depth is usually relatively shallow (<10 m), with backfilling not being required (Audibert & Huang, 2005).

### 2.2.5. Vane Shear Test (VST)

The vane shear test (VST) is an in-situ method used to determine the undrained shear strength of very soft to soft cohesive seabed sediments. The test is carried out by hydraulically pushing a steel rod with a cruciform shear vane enclosed within a protective casing into the seabed to the required depth, after which the vane is extended into the sediment and rotated at a controlled rate. The measured torque required to shear the soil is used to derive undrained shear strength values, providing high-resolution strength information in soft sediments where penetration resistance-based methods may be less effective. No soil samples are recovered during testing, and due to the small probe diameter, no backfilling is required following completion of the test (Audibert & Huang, 2005).

### 2.2.6. Dynamic Probe (Heavy) (DPH)

Dynamic probing (heavy) (DPH) is a rapid in-situ testing method used to assess the relative density and strength of near-surface seabed sediments. The test involves driving a steel cone into the seabed using repeated impacts from a drop hammer, with penetration achieved by progressively adding steel rods as depth increases. Ground resistance is assessed by recording the number of hammer blows required to achieve fixed penetration increments, typically 100 millimetres (mm), allowing variations in sediment strength and stratigraphy with depth to be inferred until refusal is reached. The method does not recover samples and, due to the small probe diameter, does not require backfilling following completion of the test (Audibert & Huang, 2005).

### 2.2.7. Sediment Grabs

Sediment grabs (e.g. day grab, Hamon grab, Van Veen grab) are used for sampling seabed sediments. They are dropped via cable to the seabed, where the jaws of the grab shut on impact, collecting a surface sediment sample (typically the top 15 – 20 cm) with volume sampled depending on the grab size, sediment type, and depth. Hammon Grabs have slightly different jaw mechanism which allows for use with coarser sediments such as gravel and shell-based sediment (Audibert & Huang, 2005).

### 2.2.8. Gravity corer

A gravity corer is a robust instrument used for collecting sediment samples from the seabed driven by weight attached, during free fall from a winch attached to the vessel. It consists of a heavy barrel with optional plastic liner and core catcher to retain soft sediments. Depending on the sediment type, it typically penetrates up to 3-6 metres, capturing the stratigraphy layers of sediment in the trap (Audibert & Huang, 2005).

## Key messages

- Site investigation surveys are essential for marine development because they characterise seabed and sub-seabed conditions and provide the data needed to inform the engineering design and subsequent construction of marine infrastructure.
- Geophysical surveys use remote sensing methods to map the seabed and sub-seabed and identify hazards, sediment types and constraints over wide areas.
- Geotechnical surveys use intrusive methods at discrete locations to directly measure ground conditions, recover samples and test sediment or rock properties with depth.
- Together, geophysical and geotechnical surveys characterise the seabed, the sub-seabed and support the development of an accurate, robust ground model which is critical for engineering design, risk reduction and safe infrastructure placement.

### 3. Key fish and shellfish species within scope

Given the scale and diversity of fish and shellfish communities in Irish waters, a comprehensive species level assessment was neither practical nor proportionate for this study. Instead, the scope was designed to focus on species that are most relevant to regulatory decision making for marine site investigation surveys, based on their ecological role, conservation status, or economic importance in Irish waters. This approach ensured that the assessment concentrated on species where potential impacts were most likely to be of concern, and where sufficient evidence existed to support meaningful interpretation, acknowledging that information for many other species remains limited.

Key fish and shellfish species for consideration within Ireland were identified by considering those with available data on spawning and nursery grounds within Irish waters from Coull *et al.* (1998), Ellis *et al.* (2021) and Irelands Marine Atlas, species listed as Critically Endangered or Endangered on Irelands Red List for elasmobranchs and freshwater fish (King *et al.*, 2011; Clarke *et al.*, 2016) and species of high commercial value (defined as top 9 species by landed value within Irish waters in 2023 (Bord Iascaigh Mhara, 2025)). The species identified are listed in Table 3.1. The list is not exhaustive and may not consider species of local commercial, ecological or conservation importance. Additionally, although cephalopods are not consistently recorded in Irish waters, they were considered within the scope of the report due to their documented sensitivity to underwater noise and their importance in commercial fisheries.

**Table 3.1. List of key fish and shellfish species within the scope of this study.**

Grouping	Species	Rationale
Pelagic	Mackerel ( <i>Scomber scombrus</i> )	Species of high commercial value. Spawning and nursery grounds within Ireland.
	Blue whiting ( <i>Micromesistius poutassou</i> )	Species of high commercial value. Spawning and nursery grounds within Ireland.
	Horse mackerel ( <i>Trachurus trachurus</i> )	Spawning grounds within Ireland.
	Herring ( <i>Clupea harengus</i> )	Spawning and nursery grounds within Ireland.
	Sprat ( <i>Sprattus sprattus</i> )	Spawning grounds within Ireland.
Demersal and benthic	Haddock ( <i>Melanogrammus aeglefinus</i> )	Species of high commercial value. Spawning and nursery grounds within Ireland.
	Monkfish ( <i>Lophius piscatorius</i> )	Species of high commercial value. Nursery grounds within Ireland.
	Cod ( <i>Gadus morhua</i> )	Spawning and nursery grounds within Ireland.
	Hake ( <i>Merluccius merluccius</i> )	Spawning and nursery grounds within Ireland.
	Ling ( <i>Molva molva</i> )	Spawning and nursery grounds within Ireland.
	Plaice ( <i>Pleuronectes platessa</i> )	Spawning and nursery grounds within Ireland.
	Sandeel	Spawning and nursery grounds within Ireland.
	Sole ( <i>Solea solea</i> )	Spawning grounds within Ireland.
	Whiting ( <i>Merlangius merlangus</i> )	Spawning and nursery grounds within Ireland.
Lemon sole ( <i>Microstomus kitt</i> )	Spawning and nursery grounds within Ireland.	

Grouping	Species	Rationale
	Saithe ( <i>Pollachius virens</i> )	Nursery grounds within Ireland.
	Megrim ( <i>Lepidorhombus whiffiagonis</i> )	Spawning and nursery grounds within Ireland.
Diadromous	Sea lamprey ( <i>Petromyzon marinus</i> )	Annex II species and protected under the Fisheries Act.
	River lamprey ( <i>Lampetra fluviatilis</i> )	Annex II species and protected under the Fisheries Act.
	Allis shad ( <i>Alosa alosa</i> )	Annex II species and protected under the Fisheries Act.
	Twaite shad ( <i>Alosa fallax</i> )	Annex II species and protected under the Fisheries Act.
	Atlantic salmon ( <i>Salmo salar</i> )	Annex II species and protected under the Fisheries Act.
	Brown/sea trout ( <i>Salmo trutta</i> )	Protected under the Fisheries Act.
	European eel ( <i>Anguilla anguilla</i> )	Critically endangered (CR) on Irelands Red List and protected under the Fisheries Act.
Elasmobranchs	Portuguese dogfish ( <i>Centroscymnus coelolepis</i> )	CR on Irelands Red List.
	Common skate ( <i>Dipturus batis</i> )	CR on Irelands Red List.
	Flapper skate ( <i>Dipturus intermedia</i> )	CR on Irelands Red List.
	Porbeagle ( <i>Lamna nasus</i> )	CR on Irelands Red List.
	White skate ( <i>Rostroraja alba</i> )	CR on Irelands Red List.
	Angel shark ( <i>Squatina squatina</i> )	CR on Irelands Red List.
	Leafscale gulper shark ( <i>Centrophorus squamosus</i> )	Endangered (EN) on Irelands Red List.
	Basking shark ( <i>Cetorhinus maximus</i> )	EN on Irelands Red List.
	Common stingray ( <i>Dasyatis Pastinaca</i> )	EN on Irelands Red List.
	Undulate ray ( <i>Raja undulata</i> )	EN on Irelands Red List.
	Spurdog ( <i>Squalus acanthias</i> )	EN on Irelands Red List. Nursery grounds within Ireland.
	Spotted ray ( <i>Raja montagui</i> )	Nursery grounds within Ireland.
	Thornback ray ( <i>Raja clavata</i> )	Nursery grounds within Ireland.
	Tope ( <i>Galeorhinus galeus</i> )	Nursery grounds within Ireland.
Shellfish - crustaceans	Nephrops ( <i>Nephrops norvegicus</i> )	Species of high commercial value. Spawning and nursery grounds within Ireland.
	Brown Crab ( <i>Cancer pagurus</i> )	Species of high commercial value.
	Lobster ( <i>Homarus gammarus</i> )	Species of high commercial value.
Shellfish - molluscs	Scallop ( <i>Pecten maximus</i> )	Species of high commercial value.
	Whelk ( <i>Buccinum undatum</i> )	Species of high commercial value.
	Native oyster ( <i>Ostrea edulis</i> )	Commercially important species*
	Pacific oyster ( <i>Magallana gigas</i> )	Commercially important species*
	Blue mussel ( <i>Mytilus edulis</i> )	Commercially important species*

\*These species were included as the 3 most commercially important species in the Irish shellfish aquaculture industry (Bord lascaigh Mhara, 2024; Marine Institute and Bord lascaigh Mhara, 2024).

## Key messages

- The scope focuses on species with clear ecological, conservation and economic relevance for regulatory decision making in Ireland, to ensure that the review concentrates on species where potential impacts are most likely to be of concern for assessing MUL applications.
- These include pelagic, demersal, benthic, and diadromous fish, elasmobranchs and shellfish
- Rationale for species inclusion was based on available data on spawning and nursery grounds within Irish waters, species listed as Critically Endangered or Endangered on Ireland's Red List for elasmobranchs and freshwater fish, species of high commercial value (defined as top 9 species by landed value within Irish waters in 2023) and the 3 most commercially important species for shellfish aquaculture in Ireland.

## 4. Key impacts of site investigation surveys on fish and shellfish

Based on available scientific evidence, two key impact pathways relevant to site investigation surveys were identified for fish and shellfish in Irish waters: underwater noise and physical disturbance of the seabed. The sections below describe the potential effects associated with each impact pathway in the context of fish and shellfish in Irish waters.

### 4.1. Impacts from Underwater Noise

A systematic literature review of peer-reviewed papers and grey literature identified 49 key publications on the impacts of underwater noise on fish and shellfish, primarily focused on the impact of impulsive noise (30 papers) compared to continuous noise (19 papers). Of the 30 papers on impulsive noise, 25 studied the impacts of air guns in the field on fish and shellfish, while the remaining 5 used tank playbacks of impulsive noise regimes. Of the 19 papers on continuous noise, 18 studied the impacts of continuous noise using tank playbacks, with only one studying in-situ effects of a marine vibration noise on Atlantic cod. It is important to note that substantial knowledge gaps in the literature were identified. Impulsive noise impact studies to date are almost entirely limited to air gun seismic sources, with no available evidence found on the impacts of other geotechnical or geophysical impulsive noise sources. Continuous noise impacts are inferred almost entirely from laboratory studies that expose fish and shellfish to playbacks simulating continuous motorboat noise or white noise, which may not reliably represent continuous geophysical and geotechnical sources of noise in the marine environment. However, these studies remain valuable as they provide evidence for analogous underwater noise impacts on fish and shellfish.

Underwater noise and sound play a crucial role in the life history of many fish and shellfish species, supporting essential behaviours such as navigation, foraging, prey detection, communication, and the maintenance of social structures (Hawkins and Popper, 2018; Hawkins and Picciulin, 2019; Ladich, 2019). Underwater noise can refer to both particle motion (vibration of particles caused by sound waves) and sound pressure. In fish, hearing involves the ability of otolithic organs or swim bladder structures to sense sound pressure and particle motion, which stimulate the inner ear relative to the sensory epithelium (Carroll *et al.*, 2016). Otolithic organs are present within the ears of teleost fish and each contains a mass of solid calcium carbonate crystals, known as otoliths, which are highly involved in the functioning of the inner ear in balance and hearing (Popper *et al.*, 2005). For invertebrates, sound detection often occurs through statocysts, epidermal hair cells and setae, which are sensitive to particle motion (Mooney *et al.*, 2010; El-Daiti *et al.*, 2024). Shellfish therefore do not fit within the same hearing categories as fish and are treated separately in this review.

The sensitivity of fish to underwater noise is largely determined by their anatomy, namely the presence or absence of a swim bladder, its linkage to the inner ear (and otolithic organs) and its role in hearing (Popper and Hastings, 2009; Popper *et al.*, 2014; Hawkins and Popper, 2017, 2018). The Acoustical Society of America (ASA) Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.*, 2014) are commonly used to inform underwater noise assessments for fish. Popper *et al.* (2014) broadly group fish into the following categories based on their anatomy and the available information on the hearing of other fish species with comparable anatomies:

- Fishes lacking swim bladders that are sensitive only to sound particle motion and show sensitivity to a narrow band of frequencies;
- Fishes with a swim bladder where the organ does not appear to play a role in hearing. These fish are sensitive only to particle motion and show sensitivity to a narrow band of frequencies;
- Fishes that have structures mechanically linking the swim bladder to the inner ear. These fishes are sensitive primarily to sound pressure, although they also detect particle motion. These species have a wider frequency range, and generally show higher sensitivity to sound pressure than fishes with an absence of a swim bladder or with the presence of a swim bladder which does not play a role in hearing; and
- Fish eggs and larvae.
- Shellfish (crustaceans and molluscs) are treated as a separate grouping to distinguish their different sound detection mechanisms in comparison to the fish groupings.

The species included in the scope of this study within Ireland (listed in Table 3.1) have been categorised into the above groupings in Table 4.1 as they use different sound detection mechanisms.

**Table 4.1. Anatomical groupings of the key species in Irish waters within the scope of this study, based on categories from Popper *et al.* (2014).**

Grouping	Species
1 - Lack a swim bladder	All elasmobranchs, river lamprey, sea lamprey, monkfish, sandeel, plaice, sole, megrim, lemon sole, mackerel, horse mackerel
2 - Swim bladder where the organ does not appear to play a role in hearing	Blue whiting, haddock, cod, whiting, saithe, hake, ling, Atlantic salmon, European eel, brown/sea trout
3 - Structures mechanically linking the swim bladder to the ear	Herring, sprat, allis shad, twaite shad
4 - Larvae and eggs	Those species above during early life stages
5 - Shellfish (crustaceans and molluscs)	Nephrops, brown crab, scallop, lobster, whelk, native oyster, pacific oyster, blue mussel

Many studies in the following literature review draw on the impacts of noise on species that are not typical of the marine environment in Ireland. The anatomical groupings assigned to Irish fish species in Table 4.1 above have been applied to the species considered in the literature review to allow contextualisation and inference of potential effects on Irish fish species. Groupings from Popper *et al.* (2014) have been used throughout, because species with analogous or comparable hearing structures may respond similarly to different noise types, although this does not suggest that all species within a grouping will experience identical impacts. These groupings have been assigned throughout the main text, such that when a species is referenced, this grouping is in brackets following the species name e.g. (grouping 4) refers to a species within the anatomical grouping of larvae and eggs. This information is also summarised and colour coded for each study and species in Appendix II, Table 9.1 (for impulsive noise studies) and Appendix II, Table 9.2 (for continuous noise studies).

The appendix also details the sound features (contextualising sound exposure levels), the effect type (indicating the scale of impact) and the locational relevance (field or tank study). This information can be considered alongside i.e. temporal data on spawning periods (Table 7.1) and spatial data on spawning and nursery areas (Figure 7.1 and Figure 7.2) for key Irish species to assess potential sensitivity to underwater noise by geophysical or geotechnical activities and then identify when mitigation may be required.

#### 4.1.1. Impulsive Noise

Impulsive noise describes short duration, high energy sound, which can be generated by geophysical and geotechnical survey techniques such as air guns (single and arrays), SBP, CPT, borehole drilling and vibrocoring (Ruppel *et al.*, 2022). The noise can often lead to physiological changes in fish and shellfish that have been documented in literature as sublethal behavioural and injurious impacts, and in some cases moribundity and mortality. The effects are summarised in the text below and in Appendix II, Table 9.1. Most studies on impulsive noise focused on the impacts of air guns on fish and shellfish in field and tank studies, with a lack of literature available on the impacts of other impulsive sources.

##### Mortality

Across the reviewed literature, mortality associated with exposure to impulsive noise was generally reported less frequently than non-lethal effects, however, lethal effects may be underestimated due to the short-term nature of experimental studies. Instances of mortality or moribundity (near death) were primarily confined to two groups: fish eggs and larvae, and shellfish.

Christian *et al.* (2003) reported significant developmental differences and higher mortality in snow crab (*Chionoecetes opilio*) eggs (grouping 4) following exposure to air guns, compared to the unexposed control group. In relation to shellfish, Day *et al.* (2017) found that exposure to air guns over chronic timescales (months) led to increased mortality of adult Australian scallops (*Pecten fumatus*) (grouping 5). Nine giant squids (*Architeuthis dux*) (grouping 5) were reported to be stranded close to the site of a geophysical research event following acoustic air gun arrays, and when necropsied, were documented to have internal injuries including organ rupture and bruising and statocyst damage (Guerra *et al.*, 2004), however, these observations were anecdotal rather than obtained under controlled study conditions.

##### Injurious effects

Injurious effects associated with impulsive noise have been reported in the form of structural damage to sensory organs, developmental abnormalities and reflex impairment.

In fish, McCauley *et al.* (2003) found that pink snapper (*Pagrus auratus*) (grouping 2) sustained extensive, possibly permanent impairment to their sensory epithelia following exposure to air guns, with ablated hair cells. Recovery was limited, as there was no evidence of repair or replacement of damaged cells up to 58 days following exposure. In shellfish, exposure of New Zealand Scallop larvae (*Pecten novaezelandiae*) (grouping 4) to seismic pulse playbacks resulted in significant developmental delays, with 46% of the larvae studied developing morphological abnormalities (De Soto *et al.*, 2013).

Tail extension and righting response reflexes were impaired in Southern rock lobsters (*Jasus edwardsii*) (grouping 5) exposed to air guns, and statocyst damage was detected in individuals for up to a year following exposure. No mortalities or moribundity, biochemical responses or effects on fecundity, abnormality rate, competency, or energy content occurred (Day *et al.*, 2016). Exposure of northwest Mediterranean cephalopods (*Loligo vulgaris*, *Sepia officinalis*, *Octopus vulgaris*, and *Illex coindetii*) (grouping 5) to low-frequency impulsive noise sweeps for two hours resulted in permanent and substantial acoustic trauma, with damage to the sensory hair cells of the statocysts, neurons and lesions (André *et al.*, 2011; Solé *et al.*, 2013).

### **Physiological effects**

Physiological effects resulting from impulsive noise have been reported in the form of biochemical, cardiovascular and histochemical changes.

Santulli *et al.* (1999) found that variations of biochemicals including hormones and metabolites occurred in European seabass (*Dicentrarchus labrax*) (grouping 2) following air gun exposure, indicating a primary and secondary stress response. However, there was no indication of macroscopic effects on skeletal apparatus or mortality up to 72 hours following exposure, and the return of biochemical parameters within 72 hours post exposure indicates a rapid recovery ability by European seabass. Atlantic cod (*Gadus morhua*) (grouping 2) exhibited bradycardia (reduced heart rate) in response to the particle motion component of the air gun sound, indicative of an initial flight response, but no long-term physiological effects were observed (Davidsen *et al.*, 2019). A histochemical change linked to organ stress was noted in American lobsters (*Homarus americanus*) (grouping 5) that had been exposed to air guns 4 months prior, however, there were no effects on delayed mortality or physical damage to sensory systems (Payne *et al.*, 2007). In response to seismic air guns, La Bella *et al.* (1996) found a stress response suggested from altered hydrocortisone, glucose and lactate levels in exposed bivalve Golden Carpet Shell (*Polititapes aureus*) (grouping 5) compared to control groups (Moriyasu *et al.*, 2004).

### **Behavioural effects**

Behavioural effects associated with impulsive seismic noise exposure are most frequently reported among all adverse effects and have been observed as displacement, changes in commercial catch rates, swimming behavioural changes (i.e. dropping to deeper depths, milling in compact schools, “freezing”, or becoming more active), altered foraging behaviour and alarm responses. There is also the potential for impulsive noise to alter mating behaviour. These responses can often be associated with physiological changes.

Many studies have noted catch rate changes in fish and shellfish due to displacement following air gun exposure. The lesser sandeel (*Ammodytes marinus*) (grouping 1) was assumed to be displaced in response to air guns following an observed temporary drop in landings by Norwegian sandeel trawlers for a short period following a seismic air gun shooting event (Hassel *et al.*, 2004). Similarly, following air gun arrays in Norway, changes in catch rates of many fish species were detected, when using gillnets and longlines targeting redfish (*Sebastes norvegicus*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*) and ling (*Molva molva*) (grouping 2), and Greenland halibut (*Reinhardtius hippoglossoides*) (grouping 1) suggesting displacement of these groups (Løkkeborg *et al.*, 2012). In

Adriatic sea shellfish, catch rates were negatively impacted due to suspected displacement in the purple dye murex gastropod (*Bolinus brandaris*) (grouping 5), following exposure to air guns (La Bella *et al.*, 1996; Moriyasu *et al.*, 2004).

Air guns have been noted to alter short and long term swimming and foraging behaviour. European seabass (grouping 2) increased their swimming speed and demonstrated altered swimming depth and group cohesion, with greater effects during the night, in response to impulsive brown noise exposure (Neo *et al.*, 2018). Atlantic cod (grouping 2) in the southern North Sea reduced foraging behaviour and were displaced, with diurnal activity cycles disrupted (van der Knaap *et al.*, 2021). Following exposure, these cod left the study area between 2 days and 2 weeks following the survey in contrast to their normal residency times. This is in agreement with findings from Hubert *et al.* (2020), who found that many individual Atlantic cod changed their usual time spent in different behavioural states in response to simulated air gun sounds in tanks, although they did not change swimming patterns immediately. Rockfish (*Sebastes* spp.) (grouping 2) indicated acute responses to air guns, demonstrating alarm and startle responses, increased activity and vertical shifts and tighter schooling, however returned to normal behaviour within 60 minutes (Pearson *et al.*, 1992). Atlantic cod and saithe (grouping 2) changed swimming depth and horizontal position more frequently during air gun noise production, although no behavioural startle response to the air gun was noted. Saithe became more dispersed in when experiencing elevated sound levels, however all fish were observed to habituate behaviourally with repeated exposure and there appeared unlikely to be long term behavioural alterations (Davidsen *et al.*, 2019). A change in food consumption by American lobsters (grouping 5) for several weeks to months following air gun exposure was measured by Payne *et al.*, 2007, which was suggested by the authors to indicate an overall disturbance in metabolic rate or perturbation of neural or endocrine functions associated with feeding (Payne *et al.*, 2007).

Startle and alarm responses to impulsive noise have been reported by many fish species. Juvenile saithe, cod and adult pollock (*Pollachius pollachius*) (grouping 2) and mackerel (*Scomber scombrus*) (grouping 1) exhibited rapid escape startle reflexes at onset of air gun shots, however exhibited no substantial or permanent behavioural changes or displacement throughout the course of the study (Wardle *et al.*, 2001). Other species that demonstrated alarm responses include trevally (*Pseudocaranx dentex*) and pink snapper (grouping 2), Southern reef squid (*Sepioteuthis australis*) (grouping 5), which ejected ink (Fewtrell and McCauley, 2012), snappers (*Lutjanus synagris* and *Lutjanus apodus*) and Atlantic spadefish (*Chaetodipterus faber*) (grouping 2) which showed no obvious short-term deleterious effects but a clear startle response in the form of a temporary increase in swimming velocity and direction, showing habituation after repeated exposure (Boeger *et al.*, 2006). Southern reef squid (grouping 5) showed alarm responses involving ink ejection and rapid swimming at an estimated 2-5 km from an approaching large seismic source (McCauley *et al.* 2000).

Additionally, air gun noise can lead to auditory masking and reduced communication ranges in Atlantic cod (grouping 2) (Pine *et al.*, 2020), which poses implications for mating behaviour and mate choice.

### **No effects**

Despite the above, there were numerous studies that found no significant adverse effects of impulsive noise on fish and shellfish species in various classification types.

In fish, for example, there were no effects of air gun exposure on the composition, abundance, size structure, behaviour, or movement of tropical demersal fish over a period of weeks to months (Meekan *et al.*, 2021). McQueen *et al.* (2022) found that tagged Atlantic cod (grouping 2) were not significantly displaced from spawning grounds following exposure, and there were no effects on swimming behavioural changes, suggested due to the relatively distant proximity to the seismic surveys (at 115 - 145 dB re 1 $\mu$ Pa<sup>2</sup>s over 5 days). In shellfish, no evidence was found on mortality or productivity of Silverlip Pearl Oyster (*Pinctada maxima*) (grouping 5) (Parsons *et al.*, 2024), Australian scallop and Austral scallop (*Mimachlamys asperima*) (grouping 5) (Przeslawski *et al.*, 2018), nor mortality rate and adductor muscle strength of Australian scallop or bivalve larvae (grouping 4) in the plankton close to the seismic survey (Parry *et al.*, 2002). There were no deleterious effects on bottom trawl yields of various shrimp species (grouping 5) in Brazil (Andriguetto-Filho *et al.*, 2005). In adult snow crab (grouping 5), Courtenay *et al.* (2009) there was no attributable acoustic injury caused by air gun noise.

#### 4.1.2. Continuous Noise

Continuous noise describes long-duration non-impulsive sound that can be emitted from sources such as marine vibrators, MBES, SSS, and low- and mid-frequency naval sonar (Popper *et al.*, 2014). The noise can often lead to physiological changes in fish and shellfish that have been documented in literature as sublethal behavioural and injurious impacts, and in some cases moribundity and mortality. The effects are summarised in the text below and in Appendix II, Table 9.2. There were very limited field studies focused on the impacts of continuous noise originating from geotechnical or geophysical sources on fish and shellfish. Most papers here document the impacts of continuous noise associated with shipping playback sounds or white noise within tank studies, with the exception of McQueen *et al.* (2024), who document the effects of marine vibrator noise on rainbow trout (grouping 2). Additionally, because most of these studies were conducted *ex situ* in a laboratory, the results may not reflect the realistic impacts of continuous seismic noise exposure on the species studied compared to those in the marine environment.

##### **Mortality and Injurious effects**

Across the literature reviewed, no instances of direct mortality or injury were found to have occurred directly from continuous noise exposure, however indirect mortality has been noted to have the potential to occur as a result of behavioural changes, for example, Lagardère (1982) found increased instances of cannibalistic behaviour in brown shrimp (grouping 5) following exposure to continuous noise playback in a laboratory.

##### **Physiological effects**

Physiological effects associated with continuous noise have been reported in terms of increased energy expenditure, stress indicators, and reduced reproductive success.

In fish, European sea bass and gilthead sea bream (*Sparus aurata*) (grouping 2) experienced a significant increase in movement and blood metabolite levels (lactate and haematocrit) following exposure to a 10-minute continuous noise sweep. In the gilthead sea bream, glucose levels decreased significantly, which the authors suggested may compromise metabolically costly activities such as

foraging, migration, and reproduction (Buscaino *et al.* 2010). Similarly, in a separate study, gilthead sea bream exposed to continuous noise for 10 days showed a significant increase in blood plasma biochemical components (including ACTH, cortisol, glucose, lactate, haematocrit, cholesterol, triglycerides etc), indicating a stress response (Celi *et al.*, 2016). Additionally, following 1 month of chronic continuous noise exposure, the lined seahorse (*Hippocampus erectus*) (grouping 2) displayed chronic stress responses, increased susceptibility to parasites, lower weight, worse body condition and higher plasma cortisol, which the author suggested would all have implications for the animal's energy budget for growth, condition, and immune status (Anderson *et al.*, 2011). After experiencing a sweep of continuous noise, Atlantic cod (grouping 2) displayed higher cortisol levels than control groups, indicating heightened levels of stress, which returned to baseline levels < 1 h after sound exposure ended (Sierra-Flores *et al.*, 2015). Furthermore, when sound was played during spawning windows to a broodstock population of cod, a 50% reduction in egg production and fertilisation rates occurred, negatively impacting spawning success (Sierra-Flores *et al.*, 2015) and highlighting potential reproductive consequences of noise-induced stress on fish. Continuous noise caused elevated metabolic stress within damselfish (*Pomacentrus amboinensis*) (grouping 2), which was found to impact their anti-predator behaviour in the form of responding less often and less quickly to predator strikes, increasing their predation susceptibility (Simpson *et al.*, 2016).

In shellfish, shore crabs (*Carcinus maenas*) (grouping 5) exposed to continuous ship noise playback consumed 67% more oxygen with a higher metabolic rate, assumed due to stress, which was more pronounced in heavier crabs, indicating a size-dependent response (Wale *et al.*, 2013). Brown shrimp (*Crangon crangon*) (grouping 5) reared in continuously high sound environments showed a rapid increase in metabolic rate within hours of exposure, with no evidence of adaptation after 5 days (Regnault and Lagardere, 1983). In the same species, Lagardère (1982) found a higher instance of disease and significant reduction in growth and reproduction rate in exposed animals, with fewer egg bearing females compared to control groups in short term (after 2 months: 50% vs 80% respectively) and long term (3 months: 70% vs 92%) (Lagardère, 1982). Wale *et al.* (2019) found shipping noise-induced changes in DNA integrity in the blue mussel (*Mytilus edulis*) (grouping 5), specifically DNA single strand breaks in haemocytes and gill epithelial cells, and oxidative stress within gill tissues. In European spiny lobster (*Palinurus elephas*) (grouping 5), continuous shipping playback led to a stress response and an increase in biochemical parameters such as proteins and haemocytes, which could lead to an impaired immune response (Celi *et al.*, 2015). The blue mussel (grouping 5) exhibited a 12% reduction in oxygen consumption, a 60% increase in valve gape and an 84% reduced filtration rate when exposed to shipping noise, with implications for its capacity to build reefs (Wale *et al.*, 2019).

### **Behavioural effects**

Behavioural effects associated with continuous noise have been reported in the form of changes in typical cannibalistic and anti-predator behaviour, swimming, foraging and bioturbation (the reworking of soils and sediments by animals) activity changes. These responses can often be associated with physiological changes.

Spawning Atlantic cod (grouping 2) exposed to continuous seismic noise from a marine vibrator displayed altered swimming activity and depths, but were not displaced (McQueen *et al.*, 2024). In certain animals, behavioural changes were not chronic. For example, the lined seahorse (grouping 2) displayed irritation behaviour (tail adjustment), pathological and distress behaviours including piping

and clicking, but habituated after a week (Anderson *et al.*, 2011). Atlantic cod (grouping 2) experienced short-term avoidance behaviour in response to the noise, showing temporary distributional changes but not permanent changes (Mueller-Blenkle *et al.*, 2008).

In shellfish, brown shrimp (grouping 5) reared in continuously elevated sound levels exhibited increased aggression, cannibalism and disease (Lagardère, 1982). They also had a decreased food uptake indicating a stress response compared to controls (Lagardère, 1982). Bioturbation activities of shellfish are also affected by continuous noise. In Nephrops (*Nephrops norvegicus*) (grouping 5), there was no effect on tissue biochemicals (concentrations of glucose or lactate), however they showed reduced locomotion, repressed burying and bio irrigation behaviour. Clams (*Ruditapes philippinarum*) (grouping 5) elicited a suspected stress response whereby individuals reduced their surface relocation activity, moved to a position above the sediment-water interface and closed their valves. These responses reduce the capacity of the organism to mix the upper sediment profile and prevent suspension feeding from taking place (Solan *et al.*, 2016). Charifi *et al.* (2017) found that for Pacific oyster (*Magallana gigas*) (grouping 5) showed transient valve closure and startle response. Continuous noise was suggested to negatively impact predator response behaviour in shore crabs and hermit crabs. Exposed shore crabs (*Hemigrapsus oregonensis*) (grouping 5) had increased instances of non-directional movement compared to the control group, which is atypical, as freezing or moving in response to a predator are normal crab anti-predator behaviours (Birch *et al.*, 2025). European hermit crabs (*Pagurus bernhardus*) (grouping 5) were less likely to accept an optimal shell during exposure to noise which suggests that the noise disrupts the sensory information gathering process (Tidau and Briffa, 2019).

### **No effects**

Multiple studies documented no clear effects of continuous noise on fish and shellfish.

There was no mortality found within rainbow trout (*Oncorhynchus mykiss*) (grouping 2), during or after exposure to low-frequency active sonar playback noise (long tones and sweeps) (Popper *et al.*, 2007). Analysis of sensory tissue within the trout inner ears did not show any morphological damage several days post-sound exposure, and additionally, gross and histopathology observations demonstrated no effects on nonauditory tissues (Popper *et al.*, 2007). In whiteleg shrimp (*Litopenaeus vannamei*) (grouping 5) and Atlantic salmon (*Salmo salar*) (grouping 2), no effects of continuous sounds were detected in terms of growth, survival or blood biochemistry, potentially due to habituation to the noise (Slater *et al.*, 2020). Continuous boat noise had no effect on cortisol levels in giant kelpfish (*Heterostichus rostratus*) (grouping 2) (Nichols *et al.*, 2015) and European seabass (grouping 2) showed no stress responses to continuous noise (Radford *et al.*, 2016), whilst both showed stress responses on exposure to less predictable, random or intermittent impulsive noise (Nichols *et al.*, 2015; Radford *et al.*, 2016).

#### **4.1.3. Discussion on the impacts of Underwater Noise on fish and shellfish**

When discussing any lack of impacts on fish and shellfish, it is important to note some clear limitations. These limitations mean that studies reporting no effects should be interpreted cautiously when assessing potential impacts by geophysical and geotechnical surveys.

Many experimental studies on underwater noise impacts are limited by the experimental design that can confound results. There are challenges with studying displacement or mortality of commercially targeted species and establishing true control sites over large spatial scales, and therefore many studies operate at unrealistic scales (Meekan *et al.*, 2021). Many studies do not measure all sublethal endpoints, so impacts may not have been captured. Evidence shows that impulsive (as outlined in section 4.1.1., mainly from air gun surveys) and continuous (as outlined in section 4.1.2.) noise can lead to auditory masking, reduced communication ranges in species such as Atlantic cod (Pine *et al.*, 2020) and hearing loss (de Jong *et al.*, 2020), with possible implications for predator avoidance and reproduction even when no observable impacts may be measured experimentally.

Impacts of impulsive and continuous noise are debated, and species responses are likely to depend on the acoustic characteristics of the source, the anatomical hearing grouping of the receptor, the life stage exposed, and the predictability and duration of exposure. For some species, the predictability of continuous noise may allow habituation and lower stress and injury than irregular impulsive sources (de Jong *et al.*, 2020), as shown experimentally in giant kelpfish (*Heterostichus rostratus*) (grouping 2) (Nichols *et al.*, 2015) and European seabass (*Dicentrarchus labrax*) (grouping 2) (Radford *et al.*, 2016). In contrast, Atlantic cod (*Gadus morhua*) (grouping 2) were more strongly affected by continuous marine vibrator noise than by air guns at similar exposure levels, with authors suggesting that gaps between impulsive sounds may allow fish to maintain communication and listening ability between pulses (McQueen *et al.*, 2024).

For the purposes of Maritime Usage Licence assessment in Irish waters, the current evidence suggests that impulsive noise is most consistently associated with behavioural effects, including startle responses, avoidance, displacement, altered swimming behaviour and reduced foraging, particularly for fish in groupings 1 and 2, which include several key Irish receptors such as mackerel, flatfish, cod, haddock, saithe, hake and ling. More severe effects, including injury, developmental abnormalities and occasional mortality, are more strongly evidenced for eggs and larvae (grouping 4) and shellfish (grouping 5), although the evidence base for these outcomes is derived largely from seismic air gun studies rather than routine site investigation sources. Continuous noise, by contrast, is more consistently associated with chronic sublethal effects, particularly physiological stress, increased metabolic demand, altered behaviour and, in some cases, reduced reproductive success, with strongest relevance to fish in grouping 2 and shellfish in grouping 5.

For common site investigation surveys in Irish waters, this suggests that impulsive geophysical methods are likely to present lower risk than large seismic air gun sources in most cases, while continuous geophysical sources are more likely to result in local, sublethal and context-dependent disturbance rather than direct injury. In practice, the main implications for MUL assessment are that timing and location are critical. Particular caution is warranted where surveys overlap spawning grounds during spawning periods, nursery areas, or sensitive shellfish habitats such as Nephrops grounds, oyster beds and other important benthic habitats, and where continuous or repeated survey activity may prolong exposure near sensitive receptors.

## 4.2. Impacts from physical disturbance (other than noise)

A systematic literature review of over 50 papers on physical disturbance impacts on fish and shellfish identified 38 key publications, primarily through habitat loss or removal (18 papers) and suspended sediments or smothering (29 papers). Surprisingly, none provided empirical data specific to impacts of geotechnical surveys on fish or shellfish, representing a major knowledge gap in our understanding of this topic. This could also represent a low perceived impact of geotechnical survey methods on the marine environment, including fish and shellfish. Consequently, this section draws on evidence from other seabed-disturbing activities (bottom fishing, dredging, exploratory drilling for oil and gas and marine aggregate extraction) to describe plausible impact pathways (habitat loss or removal and sediment resuspension or smothering) and key drivers of sensitivity and recovery (notably habitat type, hydrodynamics and life stage). It must be emphasised that these other marine activities are typically conducted at far greater spatial and temporal scales than geotechnical surveys and as such their results are used to inform pathway relevance and relative sensitivity, rather than to provide directly comparable effect magnitudes (Foden et al., 2011; Kaiser et al., 2006).

### 4.2.1. Habitat loss or removal

Studies on shellfish dredging and other forms of commercial bottom fishing demonstrate that habitat removal causes direct mortality and long recovery times (several years) for certain benthic communities to recolonise affected habitat (Kaiser et al. 2006). Kaiser et al. (2006) conducted a global meta-analysis of 101 experimental fishing-impact studies and found that towed gears consistently reduced abundance and biomass of benthic fauna, with the most severe and long-lasting effects in biogenic and coarse sediments, especially from scallop dredges on gravel and reef habitats (up to 8 years recovery). More homogenous habitat types like muddy sands and other soft sediments showed quicker recovery times in comparison. Kenny and Rees (1996) documented that a single gravel-dredging event removed much of the macrobenthos and reduced biomass by over 90%. Though opportunistic species recolonised within about a year, total biomass and rarer taxa remained depressed for two years. At a broader scale, Foden et al. (2011) estimated that benthic trawling and dredging affected over half of the seabed of England and Wales through abrasion, with typical benthic recovery times of 1 - 8 years depending on gear, habitat, and hydrodynamics. Recovery was prolonged to 10 - 15 years in sand and gravel when fishing ground overlapped with aggregate extraction.

While geotechnical surveys generally occur at much smaller spatial scales than bottom fishing and dredging, the relevance of these studies is greatest for intrusive geotechnical methods that physically remove or displace sediment and create a discrete excavation or borehole in the seabed, such as boreholes, rotary coreholes, vibrocores and, to a lesser extent, sediment grabs. The habitats and benthic communities shown to be most sensitive to physical removal or alteration in dredging and fishing studies are therefore relevant for understanding where these more intrusive geotechnical methods may be ecologically consequential. On this basis, where such methods intersect structurally complex or low-resilience habitats such as biogenic reefs, coarse gravels or mixed substrates, even small-scale disturbance has the potential to result in localised benthic mortality, temporary prey loss and short-term displacement of demersal species. However, there is currently no direct empirical evidence demonstrating these effects for geotechnical surveys, and confirmation would require targeted Before-After Control-Impact (BACI) field studies.

Monitoring of exploratory oil and gas drilling further illustrates the potential consequences of intensive, localised seabed disturbance. Jones *et al.* (2006) found that prior to exploratory drilling, benthic megafauna exhibited highly heterogeneous distributions, whereas post-drilling the disturbed area (~28,400 m<sup>2</sup>) showed markedly reduced megafaunal abundance, indicating substantial local habitat loss. Gates *et al.* (2012) similarly documented pronounced reductions in megafaunal density following drilling at 380 m depth in the Norwegian Sea, with densities declining from 0.21 individuals m<sup>-2</sup> pre-disturbance to 0.08 – 0.10 individuals m<sup>-2</sup> immediately after drilling and to 0.05 individuals m<sup>-2</sup> three years later, reflecting slow habitat recovery. These changes are consistent with direct removal or degradation of benthic habitat, leading to loss of infaunal and epifaunal communities that underpin prey availability and refuge for demersal fish and shellfish.

By comparison, geotechnical surveys typically operate at much shallower depths (approximately 5–100 m), use smaller-diameter sampling methods (generally <20 cm), and affect seabed areas that are orders of magnitude smaller than those associated with oil and gas drilling. Habitat loss associated with geotechnical surveys is therefore expected to be confined to very small, discrete footprints corresponding to individual boreholes or sampling locations. Any effects on fish and shellfish are anticipated to be highly localised, with greatest sensitivity among sessile benthic infauna and epifauna occupying the immediate survey footprint, while mobile demersal fish and crustaceans are likely to temporarily avoid the disturbed area. In some cases, small-scale habitat alteration may result in short-term changes in species composition, including opportunistic colonisation, representing localised habitat modification rather than substantive habitat loss. However, the extent and ecological relevance of such effects for geotechnical surveys in Irish waters remain uncertain and would require targeted field investigations to be confirmed.

Marine aggregate extraction causes substantial alteration of seabed habitats through sediment removal, reprofiling and structural simplification, often resulting in direct benthic mortality and protracted recovery. Last *et al.* (2011) documented that capital dredging on the Hastings Shingle Bank lowered the seabed by up to 2 m, stripped fine sediments and reduced infaunal abundance and biomass, with some taxa remaining depleted years after extraction under intense dredging pressure. Recolonisation favoured opportunistic small invertebrates, while larger, longer-lived gravel-community species recovered slowly or failed to recover, leading to shifts in habitat quality. These changes imply direct mortality during extraction (entrainment and burial) and indirect effects for demersal fish, shellfish and crustaceans via loss of three-dimensional structure, depleted prey availability and altered predator–prey dynamics in structured gravel and mixed sediments. In the context of geotechnical surveys, direct mortality of benthic infauna and epifauna may occur within the immediate vicinity of sampling locations, followed by a temporary reduction in benthic diversity and prey availability for mobile fish and crustaceans until recolonisation occurs. Evidence from aggregate extraction and dredging indicates that recovery trajectories differ markedly by habitat type, with faster recovery generally observed in homogeneous soft sediments and slower recovery in coarse or structurally complex substrates, including gravels and reefs (Jones *et al.*, 2006; Foden *et al.*, 2011; Gates *et al.*, 2012). Foden *et al.* (2009) report gravel habitats taking up to nine years to recover post-extraction compared to approximately 7.3 years for sandy sediments. These findings indicate that where geotechnical surveys intersect coarse or low-resilience habitats, localised effects may persist longer than in soft-sediment environments, particularly if disturbance is repeated. Although dredging is a separate activity under Schedule 7 of the MAP Act (2021) and is outside the scope of this review, evidence from dredging and aggregate extraction remains relevant here as an analogue for

understanding habitat sensitivity and recovery following physical sediment removal. However, the spatial extent of such effects is expected to remain confined to the immediate vicinity of individual sampling locations.

#### 4.2.2. Suspended Sediments or smothering

Sediment resuspension from geotechnical surveys, arising from physical disturbance by equipment such as borehole drilling, vibrocores, CPTs and sediment grabs, represents a primary potential impact pathway for fish and shellfish. This disturbance is expected to occur through localised, short-lived sediment plumes, resulting in near-bed smothering and temporary water-column turbidity in the vicinity of the sampling location. While no empirical data exist specifically for smothering and turbidity generated by geotechnical survey methods, potential effects can be inferred from broader evidence on seabed-disturbing activities such as dredging, aggregate extraction and oil and gas exploration or drilling (Wilber and Clarke, 2001; Wenger et al., 2017).

Increases in suspended sediment concentrations can have physiological and longer-term effects on fish, shellfish and crustaceans, including reduced feeding efficiency, altered behaviour and impaired reproductive success (Chapman et al., 2014; Kjelland et al., 2015). Sensitivity varies by taxon and life stage, with documented responses including:

- Behavioural effects, where adult fish avoid sediment plumes (e.g. herring and cod at relatively low suspended sediment levels), potentially altering foraging or predator–prey interactions (Westerberg et al., 1996; Kjelland et al., 2015).
- Physiological effects, including gill abrasion, mucus secretion and reduced oxygen uptake in fish, and reduced clearance rates, ciliary damage and energetic costs in filter-feeding bivalves (Wilber et al., 2001; Pinheiro et al., 2021).
- Early life-stage effects, with eggs and larvae generally considered most vulnerable to smothering due to impaired hatching, settlement disruption and interference with sensory and visual cues (Wenger et al., 2017).

Low-energy gravel habitats exhibit some of the slowest recovery from physical disturbance and smothering, as demonstrated by UK studies of aggregate extraction and dredge disposal sites (Foden et al., 2011). These environments, characterised by limited sediment reworking and natural flushing, may remain impacted for years due to persistent fine sediment accumulation within interstitial spaces that are critical for infaunal and epifaunal communities (Todd et al., 2015). This vulnerability is particularly relevant in Irish waters, where gravel beds act as priority spawning and nursery habitats for several commercially and ecologically important species (Franco et al., 2022). Documented sensitivities of selected species include:

- Herring (*Clupea harengus*): adhesive eggs deposited on gravel; smothering can delay hatching, reduce oxygenation and increase fungal infection risk (Blaxter, 1990).
- Atlantic cod (*Gadus morhua*): pelagic spawning with demersal pre-spawning behaviour; smothering may disrupt larval settlement cues (Franco et al., 2022).
- Sandeel (*Ammodytes marinus*; *A. tobianus*): reliance on clean, well-sorted sands; fine sediment deposition inhibits burrowing and increases juvenile mortality (Franco et al., 2022).

- European hake (*Merluccius merluccius*): demersal early life stages over gravelly or muddy-sand substrates; smothering may affect early juveniles (Franco et al., 2022).
- Blue mussel (*Mytilus edulis*): biogenic reef-forming species; smothering inhibits feeding and filtration (West, 2024).

Suspended sediment and smothering effects are well evidenced for activities such as dredging and demersal trawling, where sediment plumes can extend beyond the area of direct seabed contact through elevated turbidity and near-bed deposition (Kaiser et al., 2006; Kenny and Rees, 1996; Foden et al., 2011). These studies demonstrate that resuspended fines can reduce habitat quality via burial and reduced food delivery to suspension feeders, and that plume-driven sedimentation can prolong recovery in some habitats, particularly where natural reworking is limited (Kaiser et al., 2006; Kenny and Rees, 1996; Foden et al., 2011). While the spatial scale and persistence of plumes associated with dredging and trawling are not comparable to geotechnical surveys, they provide useful context on which receptors are most sensitive (e.g., filter feeders and early life stages) and which settings (e.g., fine sediments and low-energy environments) are most likely to retain deposited material (Wilber et al., 2001; Foden et al., 2011).

For geotechnical surveys, the most relevant analogue for smothering specifically is exploratory oil and gas drilling, because both can involve localised, point-source disturbance with the potential for cuttings or drilling-fluid-related deposition around boreholes (Gates et al., 2012; Jones et al., 2006; Cordes et al., 2016). Gates et al. (2012) documented severe local impacts on sessile fauna within drill cuttings footprints, with incomplete recovery after three years linked to persistent fine sediment capping and barium enrichment, illustrating how sustained deposition can cause long-lasting effects where contaminants or persistent fines are present (Gates et al., 2012; Cordes et al., 2016). Cumulative assessments also identify drill cuttings as an important smothering pressure at regional scales, with consequences for mobile species through avoidance, reduced prey availability and mortality of eggs and larvae (Foden et al., 2011; Wenger et al., 2017). In the context of geotechnical surveys, drilling muds or bentonite infill may generate very localised deposition around individual boreholes, but the smothering radius and plume volumes are expected to be orders of magnitude lower than those associated with oil and gas drilling; therefore, effects on fish and shellfish would be correspondingly more limited. However, the extent and persistence of such plumes from geotechnical methods in Irish waters remains poorly evidenced and should be confirmed through targeted field studies (Wilber et al., 2001; Wenger et al., 2017).

Marine aggregate extraction provides additional evidence on the ecological consequences of persistent, repeated sediment mobilisation and deposition over large areas, including prolonged recovery in low-energy gravel habitats and heightened sensitivity where spawning and nursery areas overlap with plume influence (Peterlin et al., 2019; Foden et al., 2011; Stelzenmüller et al., 2010). Studies indicate that plume-driven turbidity and deposition can affect eggs and larvae during transport from spawning to nursery grounds, reinforcing the vulnerability of early life stages to suspended sediments and smothering (Barbut et al., 2019; Wilber et al., 2001). For geotechnical surveys, these findings are best interpreted as sensitivity context rather than magnitude comparison: they support a precautionary focus on avoiding temporal and spatial overlap with sensitive life stages in gravel-dominated spawning and nursery habitats, particularly where multiple intrusive investigations may occur within the same area (Wilber et al., 2001; Foden et al., 2011).

### 4.2.3. Habitat complexity vs sensitivity to physical disturbance

Across the physical disturbance pathways reviewed, a consistent conclusion emerges from the literature on dredging, oil and gas exploration and aggregate extraction: habitat sensitivity and recovery are strongly governed by habitat complexity and resilience, irrespective of the scale of disturbance (Newell et al., 1998). Structurally complex habitats such as biogenic reefs, coarse gravels and mixed substrates are inherently more sensitive to physical disturbance, exhibit slower recovery and are more prone to prolonged changes in benthic community structure and function (Newell et al., 1998; Tillin et al., 2011). In contrast, homogeneous soft-sediment habitats such as muds and sands, which are naturally subject to frequent physical reworking, tend to be more resilient, with rapid recolonisation and limited long-term ecological consequences following small-scale disturbance (Newell et al., 1998).

When applied to geotechnical surveys, this evidence indicates that physical disturbance effects are most likely to be ecologically relevant where intrusive survey methods intersect complex, low-resilience habitats, coincide with sensitive life stages or occur repeatedly in the same area. Conversely, in extensive areas of homogeneous soft sediment, the same activities are unlikely to result in detectable or lasting effects on fish or shellfish. This gradient of habitat sensitivity is especially important given the diversity of broad benthic habitat types in Irish waters (Figure 4.1), and highlights the need for proportionate, habitat-led assessment and mitigation, with management effort focused on complex substrates where even small-scale disturbance may have disproportionate ecological effects. This interpretation could be strengthened by targeted field studies quantifying the footprint, persistence and recovery of disturbance from individual geotechnical methods across representative Irish habitats.

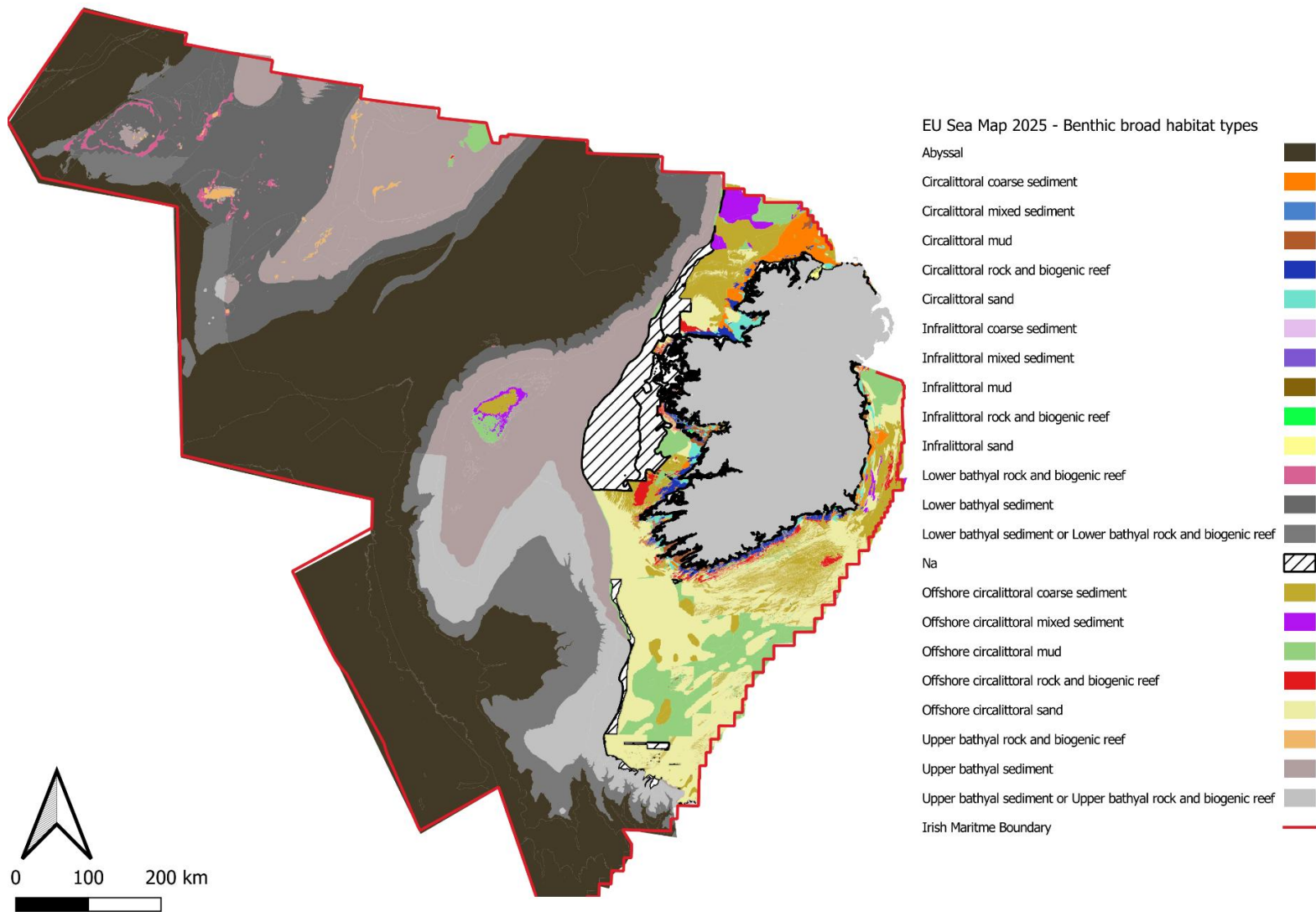


Figure 4.1 Benthic broad habitat types in Irish waters, from the Biodiversity theme of Ireland's Marine Atlas (accessed <http://atlas.marine.ie/> 03/02/2026).

### 4.3. Cumulative Impacts

Cumulative impacts arise where multiple pressures act on the same receptors in space and/or time, such that recovery between disturbance events is constrained and the net effect becomes greater than that of any single activity. In the context of Irish offshore site investigation surveys, the principal pathways for cumulative effects on fish, shellfish and crustaceans are:

- repeated or overlapping exposure to underwater noise, whether impulsive and/or continuous
- repeated seabed disturbance and associated sediment resuspension and smothering; and
- repeated disturbance associated with vessel presence and survey activity, including visual cues, vessel shadowing, dynamic positioning thrusters and local water-column turbulence.

Importantly, these pressures can act concurrently during geotechnical surveys, creating a combined disturbance “signal” to mobile fauna that is unlikely to be driven by noise, vibration, physical presence or physical disturbance in isolation.

While the direct footprints of individual geotechnical methods are typically small (boreholes are largest spatially and typically have a bore diameter of < 20 cm), cumulative effects become most relevant where surveys are clustered (multiple investigation points within a constrained development envelope), repeated (multi-season programmes and/or sequential campaigns), or co-located with sensitive habitats (e.g., structured coarse sediments, reef features, or known spawning/nursery grounds). A review of noise impacts from site investigation surveys on fisheries indicated that survey-related effects on fisheries receptors are commonly localised (order of kilometres or less) and often transient, with behavioural and catch-rate effects in some studies resolving over days to several weeks once activity ceases, although this remains inconclusive (BlueWise Marine, 2025). However, the same synthesis highlighted that cumulative risk increases where the same areas are subject to repeated survey activity without sufficient temporal separation for redistribution and recolonisation. At present, the available evidence does not define a consistent threshold for what constitutes “sufficient” temporal separation, and this is likely to depend on the receptor, habitat type, season, nature of the disturbance, and local hydrodynamic conditions.

From a behavioural perspective, the most plausible mechanism for cumulative effects of geotechnical surveys on mobile fish and shellfish is repeated avoidance and displacement driven by a combination of senses. Animals (including fish and shellfish) respond to a “multi-sensorial landscape” (sound, water disturbance, visual cues, and physical interaction) rather than a single isolated stimulus, and that responses depend on context (e.g., habitat value, life stage, and prior exposure) (Utne-Palm, 2002). In practical terms, fish may avoid an active CPT or drilling location due to the combined effect of impulsive / tonal noise and particle motion, seabed vibration, vessel or barge presence / lighting, and seabed disturbance (including local turbidity) (Wilber & Clarke, 2001; Utne-Palm, 2002; Kjelland *et al.* 2015). Where surveys overlap in time the opportunity for habituation, re-occupation, or foraging compensation can be reduced, particularly during constrained seasonal windows (e.g., spawning aggregations, demersal egg incubation, juvenile settlement) when displacement may have higher consequence (Wilber & Clarke, 2001).

Cumulative impacts also need to be framed against the existing offshore pressure landscape, where fishing and shipping are dominant drivers of seabed disturbance and noise. A European-wide

cumulative assessment found that combined effects from multiple human pressures extend across 96% of Europe's marine area, with physical disturbance affecting 86% of coastal grid cells and 46% of shelf grid cells. Within physical disturbance, fishing accounted for 55% of the pressure contribution and shipping a further 25%, reflecting the extensive footprint of bottom-contact fishing gears, alongside nearshore disturbance from shipping, ports, and anchoring (Korpinen *et al.*, 2021). The same assessment identified shipping-associated underwater noise as one of the most widespread pressures at the European scale. In Irish waters, any survey-related effects on fish and shellfish will often occur on top of background pressures from trawling / dredging (benthic abrasion, prey depletion, sediment resuspension) and shipping (continuous noise, disturbance in anchorages and approaches). The impact of a single site investigation survey may be small in isolation, but cumulative risk becomes higher when survey activity is concentrated in heavily used areas or where sensitive habitats / life stages coincide with repeated disturbance.

### Key messages

- Impulsive noise is most consistently linked to short-term behavioural effects such as startle, avoidance, displacement and reduced foraging, with more severe effects mainly reported for eggs, larvae and shellfish. The evidence base is mainly from seismic surveys and air guns.
- Continuous noise is more consistently linked to sublethal effects such as physiological stress, higher metabolic cost, altered behaviour and, in some cases, reduced reproductive success.
- Habitat loss or removal from geotechnical surveys is expected to be highly localised, but effects may be more important and longer lasting in complex, low-resilience habitats such as reefs, coarse gravels and mixed substrates.
- Suspended sediments and smothering are likely to pose the greatest risk to eggs, larvae, filter feeders and shellfish habitats, especially in low-energy environments.
- Cumulative impacts are most relevant where surveys are repeated, clustered or overlap sensitive habitats or life stages, as repeat disturbances can compile and limit recovery.

## 5. International Best Practice

A review of publicly available guidance and regulatory material did not identify a best-practice document focused specifically on the management of geophysical and geotechnical site investigation survey impacts on fish or shellfish. However, relevant best practice principles are dispersed across broader guidance for offshore renewable energy, dredging, fisheries habitat assessment, petroleum exploration and marine licensing (DCCEEW, 2023; Danish Energy Agency, 2013; Climate and Pollution Agency, 2011; BOEM and NMFS, 2023; Offshore Wind Programme Board, 2015).

In the UK, the relevant guidance is focused primarily on geophysical survey noise, especially from seismic surveys (air guns), and on reducing injury or disturbance risks to marine mammals. UK guidance highlights that controls should be scaled to source type and environmental sensitivity rather than applied uniformly across all survey methods. The guidance also emphasises early planning, identification of sensitive areas and seasons, use of the lowest practicable source levels, and source-specific controls such as pre-start searches, soft-start or ramp-up, and post-survey reporting for higher-noise activities (JNCC et al., 2010; JNCC, 2017; Offshore Wind Programme Board, 2015).

In Germany, the relevant guidance is focused primarily on offshore wind site characterisation and technical survey design, together with underwater-noise management for offshore construction activities, particularly pile driving and marine mammal protection. Best practice depends on strong survey design before intrusive works begin, and on measurable verification where higher-risk activities are proposed. Emphasis is put on desk study, hydrographic and geophysical characterisation, targeted geotechnical verification, quality assurance and formal reporting within a single staged framework. German offshore noise guidance also demonstrates the value of monitoring and verification requirements for higher-noise activities where acoustic risk is a key concern (BSH, 2014; BSH, 2023; Bellmann et al., 2020).

In the United States, relevant best practice guidance comes from the Bureau of Ocean Energy Management (BOEM) and the National Marine Fisheries Service (NMFS) assessments of offshore geological and geophysical activities, with the strongest mitigation directed at higher-noise seismic sources and protected fauna such as marine mammals and sea turtles. This guidance demonstrates that regulation should distinguish clearly between survey types and link conditions to both source characteristics and receptor sensitivity. In the US, high-resolution geophysical surveys and intrusive geotechnical survey methods are managed explicitly within offshore assessment processes, while reserving the most intensive operational controls for seismic surveys (BOEM and NMFS, 2013; NMFS, 2025).

In Australia, the relevant guidance is focused primarily on seismic survey interactions with fisheries and on broader marine-fauna risks from seismic noise. The main lesson for this report is that best practice should include stronger fisheries engagement, better use of spatial and seasonal information, and more targeted evidence gathering where uncertainty is high. Australian guidance emphasises early engagement with fisheries, identification of overlap with fishing activity and sensitive areas, and development of targeted controls through the environment plan process before surveys proceed. Australian case-study material also shows the value of baseline data, sound monitoring and before-during-after study designs where there is uncertainty about effects on fish, shellfish or fishery performance. In an Irish context, these principles are most relevant where surveys overlap shellfish

grounds, aquaculture sites or important commercial fishing areas (Australian Government, 2022; Przeslawski et al., 2016).

Across the jurisdictions reviewed, regulation of site investigation surveys appear to use a proportionate, risk-based framework in which generic conditions apply routinely and enhanced conditions are triggered by the characteristics of the receiving environment (DCCEEW, 2023; Danish Energy Agency, 2013; BOEM and NMFS, 2023). These include early identification of sensitive habitats and biologically sensitive periods, spatial avoidance of the most sensitive receptors, use of lower-impact methods where feasible, soft-start or ramp-up procedures for higher-noise activities, robust pre-survey planning, and clear reporting and communication obligations. These principles are directly relevant to site investigation surveys because the main risks to fish and shellfish are driven not simply by the survey method itself, but by the interaction between method, location, timing, and receptor sensitivity (Hawkins and Popper, 2017; Popper and Hastings, 2009; de Jong et al., 2020). In practice, this means that the same activity may require only generic controls in one location, but more targeted mitigation/conditions where it overlaps spawning grounds, nursery areas, spawning periods, migratory corridors/periods, shellfish beds, or other sensitive habitats.

### 5.1. Common Conditions relevant to an Irish context

A useful regulatory benchmark is provided by UK Marine Management Organisation marine licences granted for site investigation surveys where conditions were specifically set to avoid or protect fish or shellfish (Table 5.1). Review of these licences indicates that most environmental conditions are common across them, typically covering pollution prevention, waste removal, defined working areas, incident reporting and post-works clean-up. However, a smaller subset include targeted measures that are directly relevant to fish and shellfish. These include pre-survey screening and avoidance of sensitive benthic habitats or species, underwater noise monitoring linked to migratory fish, seasonal restrictions linked to smelt and migratory salmonids, soft-start requirements for sonic coring or drilling, and stop-work triggers where dead or distressed fish are observed. These examples are useful because they demonstrate how broad environmental principles can be translated into practical and enforceable survey-specific conditions within a comparable European licensing regime.

**Table 5.1 Examples of UK MMO site investigation licence conditions relevant to fish and shellfish receptors.**

<b>UK MMO licence example</b>	<b>Licence condition relevant to fish and/or shellfish</b>	<b>Relevance to Irish context</b>
BP/EnBW intertidal geotechnical survey (MLA/2023/00148)	Ecological Clerk of Works required during works, pre-works inspection of boreholes, no activity if protected species present; access restricted to defined working areas to minimise disturbance to sensitive species.	Useful for intertidal and nearshore Irish surveys where plant access and direct disturbance to habitats or protected species may be an important risk pathway.
Morven geotechnical and benthic survey (MLA/2023/00177)	Advance screening for sensitive benthic habitats and species, drop-down camera verification before	Strong benchmark for Irish offshore surveys in areas of reef, shellfish habitat, or other seabed

UK MMO licence example	Licence condition relevant to fish and/or shellfish	Relevance to Irish context
	works, and avoidance of sensitive features once identified.	sensitivities where pre-drill verification and micro-siting are feasible.
Solent Gateway 2 SI surveys (MLA/2025/00401)	Underwater sound monitoring required, with explicit concern for disturbance to migratory fish such as Atlantic salmon.	Relevant to Irish estuaries, ports and nearshore locations used by migratory diadromous fish.
Morgan and Morecambe River Ribble geotechnical survey (MLA/2025/00220)	Seasonal restrictions to reduce disturbance to smelt during spawning and to migratory salmonids, 20-minute soft-start for sonic coring, and stop-work if dead or distressed fish are observed.	One of the clearest examples of species-specific temporal and operational conditions that could inform licensing in estuaries and migratory fish corridors.
Isle of Man marine SI surveys (MLA/2017/00345)	Soft-start requirement, underwater sound threshold for borehole drilling, underwater noise monitoring, and submission of a post-works noise report.	Useful benchmark where verification of underwater noise predictions is required in a sensitive receiving environment.
Falmouth Docks ground investigation (MLA/2023/00253)	Soft-start drilling requirement intended to warn mobile receptors, including fish, before full-power drilling begins.	Relevant where routine nearshore drilling may affect fish in confined or sensitive coastal environments.

## 5.2. Staged approach to assessing SI survey impacts

Review of regulatory practice in other jurisdictions indicates that site investigation survey impacts are generally assessed through a staged, risk-based framework. Within this framework, the first and most important class of conditions relates to the spatial and temporal avoidance of sensitive life stages and habitats. Where surveys overlap known spawning grounds, nursery areas, shellfish beds, migratory corridors or reef habitats, applicants are often expected to justify survey timing and location and to demonstrate that lower-risk windows or micro-siting options have been considered. This is likely to be the single most effective and proportionate form of mitigation in many cases, because it reduces the likelihood of interaction with sensitive receptors.

The second class of conditions from other jurisdictions relates to pre-survey verification and adaptive micro-siting. For Irish offshore and nearshore surveys, this may include pre-drill drop-down video or ROV verification where Annex I reef, shellfish habitat, biogenic habitat, or other sensitive seabed features may be present. Where such features are confirmed, sampling locations can then be adjusted

to avoid or reduce direct disturbance. This type of condition is particularly useful where available seabed mapping is insufficiently resolved to support confident screening, or where the habitat sensitivity is high relative to the survey footprint.

The third class of conditions from other jurisdictions concerns underwater noise management. Soft-start or ramp-up procedures are most relevant to activities capable of generating higher local underwater noise, such as sonic coring, drilling, or certain impulsive geophysical survey methods. These measures are intended to provide an opportunity for mobile fish to move away from the immediate area before full operational levels are reached. In more sensitive environments, such as estuaries, transitional waters, ports, and nearshore areas used by migratory fish, there may also be a case for underwater noise monitoring, daylight-only working, or stop-work triggers where mass fish distress is observed.

The fourth class of conditions from other jurisdictions concerns sediment disturbance and seabed integrity. Direct empirical evidence for the physical impacts of geotechnical surveys on fish and shellfish remains limited, but the available evidence indicates that local turbidity, sediment deposition, prey loss, and short-term displacement may occur, particularly in sensitive or structurally complex habitats. Relevant conditions may include justification of the selected methods, management of drilling fluids and backfilling materials, limits on repeat sampling, and where appropriate, plume or turbidity monitoring. These measures are particularly important where smothering of eggs, larvae, sessile shellfish, or biogenic habitat is a plausible pathway.

The most common approach to regulation across jurisdictions is a tiered approach. Generic conditions such as pollution prevention, waste and debris removal, notification, and reporting typically remain standard across most licences for site investigation surveys. More targeted conditions are only triggered where the survey method, timing, location, or receiving environment indicates a specific risk to sensitive fish or shellfish receptors. This highlights the importance of proportional management of marine SI surveys in the Irish context.

### Key messages

- Best practice is risk-based and depends on method, place, timing and receptor sensitivity.
- Guidance is mainly focused on seismic surveys, marine mammals and offshore construction.
- Many marine survey licence frameworks use standard conditions by default and add targeted conditions only where risk of impacts to sensitive environmental receptors is higher.
- Some MMO (UK) licences have conditions relevant to minimising impacts on fish and shellfish.

## 6. Key knowledge gaps identified

The systematic literature review revealed a number of significant knowledge gaps when researching the impacts of geophysical and geotechnical surveys on fish and shellfish.

### **For geophysical surveys (underwater noise):**

- Evidence on continuous noise exposure is limited and predominantly laboratory-based, with many studies relying on playback of shipping noise or generic sound stimuli rather than capturing the characteristics of true continuous survey sources; field validation under realistic conditions remains limited.
- The evidence base for impulsive noise sources is dominated by studies on air guns, which are well studied under realistic field conditions; however, empirical studies on other impulsive sources with different acoustic characteristics are comparatively lacking.
- Key anatomical groups are poorly represented in the literature: no appropriate studies were identified for fish in grouping 3 (species with structures mechanically linking the swim bladder to the ear, such as herring and sprat), and fish in grouping 1 (species lacking a swim bladder) and grouping 4 (eggs and larvae) were absent from the continuous noise section. This limits inference for species that are present in Irish waters and may be particularly sensitive to noise.
- Knowledge gaps remain in the characterisation and classification of some common geophysical survey tools, including uncertainty around whether specific systems behave as continuous or impulsive sources at relevant ranges, complicating consistent interpretation against exposure thresholds and guidance.
- Evidence on cumulative exposure to geophysical noise under Irish shelf conditions, including repeated surveys or overlap with other anthropogenic pressures, is limited, constraining robust assessment of longer-term or population-level effects.

### **For geotechnical surveys (physical disturbance other than noise):**

- There is a clear lack of empirical studies on the impacts of geotechnical surveys on fish, shellfish and crustaceans, meaning impact assessments often rely on extrapolation from other seabed-disturbing activities. Short-term sub-lethal responses in fish, such as stress or temporary displacement, are particularly poorly quantified and require further investigation.
- Environmental guidance for geotechnical investigations is limited in most jurisdictions, with regulators typically drawing on guidance developed for other marine activities such as dredging, cable trenching, offshore energy development and deep-sea mining when considering potential impacts and mitigation requirements.
- Quantitative evidence describing sediment disturbance associated with geotechnical surveys is sparse, including method-specific information on plume extent, smothering footprint, persistence and recovery across different habitat types, limiting confidence in impact zoning and mitigation design.
- Many studies quantifying impacts of sedimentation rely on laboratory-based simulations; while these provide useful mechanistic insights, results cannot be directly translated to field conditions, and site-specific field validation remains essential.

### Some general knowledge gaps include:

- Long-term Before-After Control-Impact (BACI) monitoring of fish and shellfish responses to geophysical and geotechnical surveys, is sparse, limiting robust detection of population-level or cumulative effects arising from these activities.
- There remains a general lack of evidence linking short-term individual-level responses, such as behavioural or physiological changes, to ecologically meaningful endpoints including growth, survival, recruitment and population trends, limiting the ability to draw strong conclusions on ecological significance under realistic exposure scenarios.

### Key messages

- Evidence for survey noise impacts is uneven, with most data coming from air gun studies for impulsive noise and lab-based experiments for continuous-noise.
- Important Irish receptor groups remain poorly studied, especially fish with swim bladders that are linked to hearing, fish eggs and larvae, and some fish without swim bladders.
- There is very little direct field evidence on how geotechnical surveys affect fish, shellfish and benthic habitats, so assessments must currently rely on comparisons with other activities.
- Targeted future research could include before-after in-situ monitoring of borehole and corehole sampling locations to assess impacts of noise & physical disturbance on fish, shellfish and benthic habitats.

## 7. Recommendations

Based on the literature reviewed and the uncertainties identified, a suite of recommendations are proposed to prioritise avoidance of sensitive receptors, minimise potential impacts of site investigation surveys, and manage any residual risks to fish and shellfish.

### Pre-Survey Planning

Pre-survey desktop benthic habitat mapping, utilising Ireland's INFOMAR, Marine Atlas datasets and datasets showing the extent of spawning and nursery grounds (i.e. Coull *et al.*, 1998 and Ellis *et al.*, 2012), should delineate the spatial extent of proposed geotechnical and geophysical activities against known essential or sensitive habitats (Figure 7.1 and Figure 7.2). Temporal restrictions are recommended to avoid spawning periods of key commercial species, including Atlantic herring (*Clupea harengus*) and Atlantic cod (*Gadus morhua*) as seen below in Table 7.1 or transition periods of diadromous fish between freshwater and saltwater (Table 7.2). Where deep geotechnical investigations are proposed, hydrodynamic modelling of sediment plumes generated by drilling, drill cuttings or drilling mud release should be considered to model plume transport and deposition to quantify risk of smothering of sensitive benthic habitats (Cooper and Barry, 2017).

### Site-Specific Minimisation

It is recommended that geotechnical investigations avoid Annex I reef habitats through pre-drilling verification using Remotely Operated Vehicles (ROV) or Drop-Down Video (DDV) and undertake micro siting if feasible. Geotechnical survey methods rigged on a jack-up barge should include real-time turbidity monitoring to manage risk of impacts on sensitive fish and shellfish if present.

### Soft Start Procedures

Soft-start procedures (also termed ramp up) can be implemented for impulsive geophysical survey methods to reduce the risk of acoustic disturbance or injury to sensitive fish and shellfish. The sound source is initiated at the lowest practicable power level and gradually increased in a controlled manner over a defined period, allowing animals to detect the initial low-level noise and move away before full operational output is reached. This approach is widely recognised in national and international guidance as a key mitigation measure for minimising the environmental impacts of underwater noise during geophysical works, as well as other noise producing activities (OSPAR, 2016; JNCC, 2017).

### Cumulative Effects Management

From a cumulative perspective, the key risk-reduction principles for site investigation surveys are to (i) reduce spatial overlap with other site investigation surveys and common maritime activities such as fishing and shipping; (ii) reduce temporal overlap between survey components and between nearby projects (staggering campaigns); and (iii) Minimise survey repetition by maximising data sharing both internally and externally as well as data re-use. Temporal and spatial scheduling ensures that works are staggered to reduce cumulative disturbance to sensitive ecological receptors. Implementation will be best achieved through liaison with relevant public authorities and stakeholders.



Table 7.1: Spawning periods and peak spawning periods for selected species adapted from Coull *et al.*, 1998, and Ellis *et al.*, 2012. Light blue = spawning periods; dark blue = peak spawning.

Species	Seasonal Spawning Activity											
	J	F	M	A	M	J	J	A	S	O	N	D
Anglerfish ( <i>Lophius piscatorius</i> )	Light	Light	Light	Light	Light	Light						
Cod ( <i>Gadus morhua</i> )	Light	Dark	Dark	Light								
Whiting ( <i>Merlangius merlangus</i> )	Light	Light	Light	Dark	Dark	Light	Light	Light				
Ling ( <i>Molva molva</i> )			Light	Light	Light	Light						
Plaice ( <i>Pleuronectes platessa</i> )	Light	Dark	Light									
Lemon sole ( <i>Microstomus kitt</i> )				Light	Light	Light	Light	Light	Light			
Blue whiting ( <i>Micromesistius poutassou</i> )		Light	Light	Light								
Sandeel ( <i>Ammodytes spp.</i> )	Light	Light									Light	Light
European hake ( <i>Merluccius merluccius</i> )	Light	Dark	Dark	Light	Light	Light						
Haddock ( <i>Melanogrammus aeglefinus</i> )		Dark	Dark	Dark	Light							
Atlantic mackerel ( <i>Scomber scombrus</i> )					Light	Light	Light	Light				
Herring ( <i>Clupea harengus</i> )								Light	Light			
Norway lobster ( <i>Nephrops norvegicus</i> )	Light	Light	Light	Light	Dark	Dark	Light	Light	Light	Light	Light	Light
Sole ( <i>Solea solea</i> )		Light	Dark	Light								
Spotted ray ( <i>Raja montagui</i> )						Dark	Dark					
Sprat ( <i>Sprattus sprattus</i> )						Light	Light	Light				
Spiny dogfish ( <i>Squalus acanthias</i> )								Light	Light	Light	Light	Light
Thornback Ray ( <i>Raja clavata</i> )	Light	Light	Light	Dark	Dark	Dark	Dark	Dark		Light	Light	Light
Tope shark ( <i>Galeorhinus galeus</i> )								Light	Light			
Basking Shark ( <i>Cetorhinus maximus</i> )								Light	Light			

Table 7.2 Seasonal presence of key Irish diadromous species between freshwater, estuarine and marine water. M = marine, F = freshwater, MF = freshwater or marine, E = estuarine. EF = estuarine or freshwater (O' Leary, Brett & Poole, 2022).

Species	Freshwater vs Estuarine vs Marine presence											
	J	F	M	A	M	J	J	A	S	O	N	D
Atlantic salmon ( <i>Salmo salar</i> )	MF	MF	MF	MF	MF	MF	MF	MF	MF	MF	MF	MF
Sea trout ( <i>Salmo trutta</i> )	M	M	M	MF	MF	MF	MF	MF	F	F	F	F
European eel ( <i>Anguilla anguilla</i> )	F	F	F	F	F	F	F	M	M	M	M	M
Twaite shad ( <i>Alosa fallax</i> )	M	M	M	F	F	F	M	M	M	M	M	M
Allis shad ( <i>Alosa alosa</i> )	M	M	M	F	F	F	F	M	M	M	M	M
Flounder ( <i>Platichthys flesus</i> )	M	M	EF	EF	EF	EF	EF	EF	EF	EF	EF	EF
Thin-lipped mullet ( <i>Chelon ramada</i> )	M	M	EF	EF	EF	EF	EF	EF	EF	M	M	M
Golden-grey mullet ( <i>Chelon auratus</i> )	EF	EF	EF	EF	EF	EF	EF	EF	M	M	M	M
Sea lamprey ( <i>Petromyzon marinus</i> )	M	M	M	M	F	F	F	M	M	M	M	M
River lamprey ( <i>Lampetra fluviatilis</i> )	M	M	F	F	F	M	M	M	M	M	M	M
Smelt ( <i>Osmerus eperlanus</i> )	M	F	F	M	M	M	M	M	M	M	M	M

## Spawning Grounds by Species

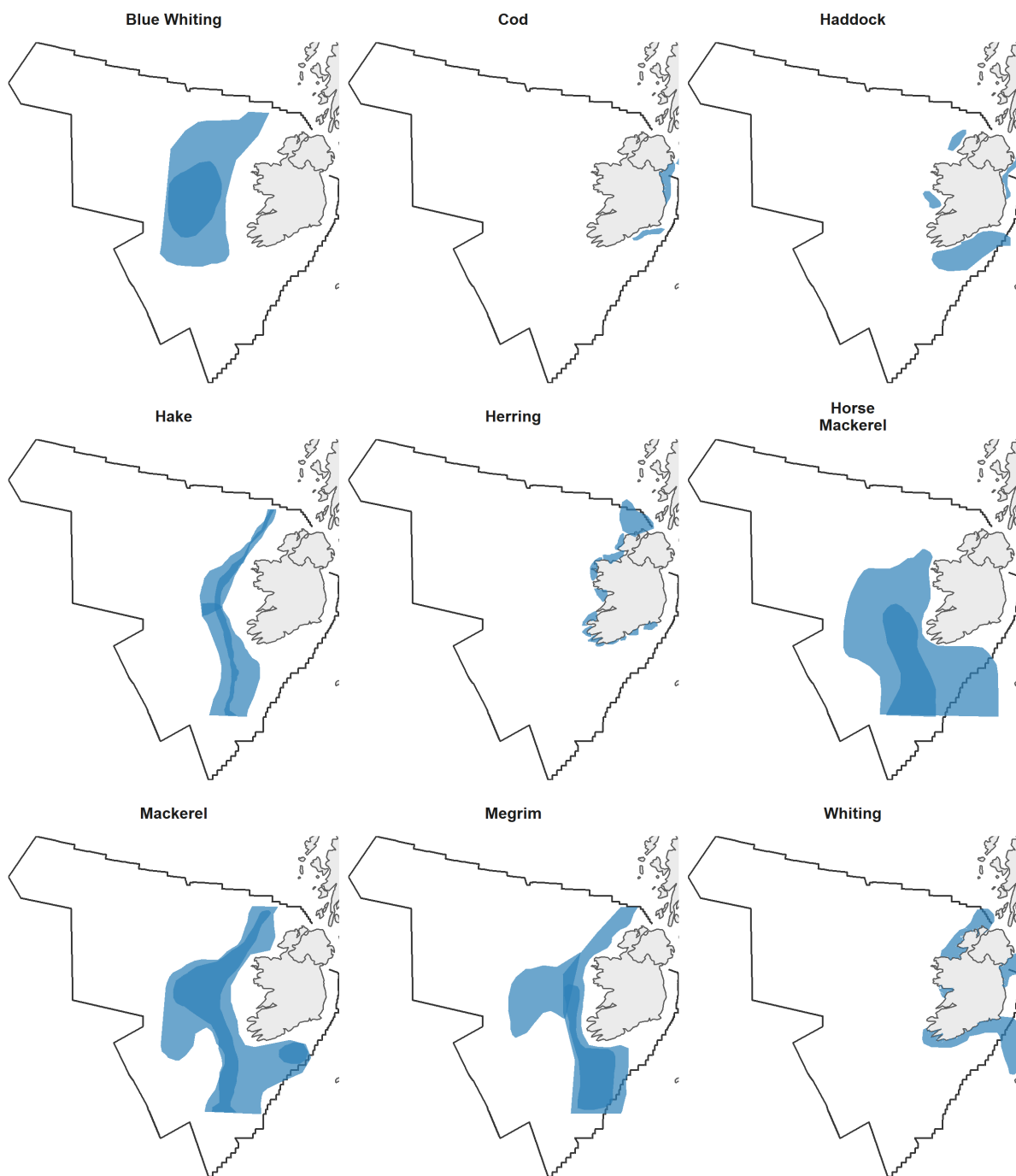


Figure 7.1 Spawning Grounds for select fish species in Irish waters. Data from the Fish Species Distribution theme accessed through Ireland's Marine Atlas at <http://atlas.marine.ie/>, 03/02/2026.

## Nursery Grounds by Species



Figure 7.2 Nursery Grounds for select fish species (green) and *Nephrops* grounds in Irish waters. Data from the Fish Species Distribution theme accessed through Ireland's Marine Atlas at <http://atlas.marine.ie/>, 03/02/2026.

## 8. References

- Anderson, P. A., Berzins, I. K., Fogarty, F., Hamlin, H. J., and Guillette Jr, L. J. (2011). Sound, stress, and seahorses: the consequences of a noisy environment to animal health. *Aquaculture*, 311(1-4), 129-138.
- André, M., Solé, M., Lenoir, M., Durfort, M., Quero, C., Mas, A., Lombarte, A., Van der Schaar, M., López-Bejar, M., Morell, M. and Zaugg, S. (2011). Low-frequency sounds induce acoustic trauma in cephalopods. *Frontiers in Ecology and the Environment*, 9(9), 489-493.
- Andriguetto-Filho, J.M., Ostrensky, A., Pie, M.R., Silva, U.A. and Boeger, W.A. (2005). Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. *Continental Shelf Research*, 25(14), 1720-1727.
- Audibert, J., & Huang, J. (2005). Chapter 16 – Geophysical and geotechnical design. In S. K. Chakrabarti (Ed.), *Handbook of offshore engineering* (pp. 1145–1268). Elsevier.
- Australian Government. (2022). Supporting cooperative coexistence of seismic surveys and commercial fisheries in Australia's Commonwealth marine area: Guidance framework.
- Barbut, L., Groot Crego, C., Delerue-Ricard, S., Vandamme, S., Volckaert, F. and Lacroix, G. (2019). How larval traits of six flatfish species impact connectivity. *Limnology and Oceanography*, 64, 1150-1171.
- Bellmann, M. A., Brinkmann, J., May, A., Wendt, T., Gerlach, S. and Remmers, P. (2020). Underwater noise during the impulse pile-driving procedure: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values.
- Birch, A., Cox, K. D., Murchy, K. A., Emry, S., and Harley, C. D. (2025). Shipping noise tolerance in invertebrates: A case study of the shore crab *Hemigrapsus oregonensis*. *Plos one*, 20(8), e0329098.
- Blaxter, J.H.S. (1990). The herring. *Biologist*, 37(1), 27-31.
- Boeger, W. A., Pie, M. R., Ostrensky, A., and Cardoso, M. F. (2006). The effect of exposure to seismic prospecting on coral reef fishes. *Brazilian Journal of Oceanography*, 54, 235-239.
- BOEM and NMFS. (2013). Endangered Species Act Section 7 Consultation Biological Opinion: Programmatic Geological and Geophysical Activities in the Mid- and South Atlantic Planning Areas from 2013 to 2020.
- BOEM and NMFS. (2023). *BOEM and NMFS EFH Assessment Template for Offshore Wind Projects*. NOAA Fisheries. Retrieved from <https://www.fisheries.noaa.gov/s3/2023-09/BOEM-NMFS-EFH-Assessment-Template-GARFO.pdf>
- Bord Iascaigh Mhara. (2025). Annual Fisheries Report 2025. Dublin: BIM. Available at: <https://bim.ie/wp-content/uploads/2025/09/Annual-Fisheries-Report-2025.pdf> (Accessed 3 February 2026).
- Bord Iascaigh Mhara. (2024). Annual Aquaculture Report 2024. Dublin: BIM. Available at: <https://bim.ie/wp-content/uploads/2025/11/Aquaculture-Survey-Report-2024-BIM.pdf> (Accessed 1 April 2026).
- BSH. (2014). Standard Ground Investigations: Minimum requirements for geotechnical surveys and investigations into offshore wind energy structures, offshore stations and power cables.
- BSH. (2023). Technical Specifications for the Central Preliminary Investigation of Sites for the Development of Offshore Wind Energy: Subsoil.
- Buscaino, G., Filiciotto, F., Buffa, G., Bellante, A., Di Stefano, V., Assenza, A., Fazio, F., Caola, G. and Mazzola, S. (2010). Impact of an acoustic stimulus on the motility and blood parameters of European sea bass (*Dicentrarchus labrax* L.) and gilthead sea bream (*Sparus aurata* L.). *Marine environmental research*, 69(3), 136-142.
- Celi, M., Filiciotto, F., Maricchiolo, G., Genovese, L., Quinci, E.M., Maccarrone, V., Mazzola, S., Vazzana, M. and Buscaino, G. (2016). Vessel noise pollution as a human threat to fish: assessment of the stress response in gilthead sea bream (*Sparus aurata*, Linnaeus 1758). *Fish Physiology and biochemistry*, 42(2), 631-641.
- Celi, M., Filiciotto, F., Vazzana, M., Arizza, V., Maccarrone, V., Ceraulo, M., Mazzola, S. and Buscaino, G. (2015). Shipping noise affecting immune responses of European spiny lobster (*Palinurus elephas*). *Canadian Journal of Zoology*, 93(2), 113-121.
- Charifi, M., Sow, M., Ciret, P., Benomar, S., and Massabuau, J. C. (2017). The sense of hearing in the Pacific oyster, *Magallana gigas*. *PLoS One*, 12(10), e0185353.
- Christian, J. R., Mathieu, A., Thomson, D. H., White, D., and Buchanan, R. A. (2003). Effect of seismic energy on snow crab *Chionoecetes opilio*. Prepared for National Energy Board, Calgary, AB., File No. CAL-1-00364. 50.
- Christiansen, B., Denda, K., Christiansen, S. (2020). Potential effects of deep seabed mining on pelagic and benthopelagic biota. *Marine Policy*, 114, 103442.
- Chartered Institute of Ecology and Environmental Management (CIEEM). (2021). Good Practice Guidance for Habitats and Species (Version 3). CIEEM, Winchester.
- Clarke, M., Farrell, E.D., Roche, W., Murray, T.E., Foster, S. and Marnell, F. (2016) Ireland Red List No. 11: Cartilaginous fish [sharks, skates, rays and chimaeras]. National Parks and Wildlife Service, Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs. Dublin, Ireland.
- Climate and Pollution Agency. (2011). Guidelines for offshore environmental monitoring: The petroleum sector on the Norwegian Continental Shelf (TA-2849/2011).
- Cordes, E., Jones, Schlacher, T., Amon, D., Bernardino, A., Brooke, S., Carney, R., DeLeo, D., Dunlop, K., Escobar-Briones, E., Gates, A., Génio, L., Gobin, J., Henry, L-A, Herrera, S., Hoyt, S., Joye, M., Kark, S., Mestre, N., Metaxas, A., Pfeifer, S., Sink, K., Sweetman, A., and Witte, U. (2016) Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. *Frontiers in Environmental Science*, 4, 58.

- Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities, L 206, 22.7.1992, pp. 7–50
- Courtenay, S., Boudreau, M., and Lee, K. (2009). Potential impacts of seismic energy on snow crab: an update to the 2004 peer review/editors: Simon Courtenay, Monica Boudreau and Kenneth Lee.
- Danish Energy Agency. (2013). Guidance document on Environmental Impact Assessment: Danish offshore wind farms. Danish Energy Agency.
- Davidson, J.G., Dong, H., Linné, M., Andersson, M.H., Piper, A., Prystay, T.S., Hvam, E.B., Thorstad, E.B., Whoriskey, F., Cooke, S.J. and Sjrursen, A.D. (2019). Effects of sound exposure from a seismic airgun on heart rate, acceleration and depth use in free-swimming Atlantic cod and saithe. *Conservation physiology*, 7(1), coz020.
- Day, R. D., McCauley, R. D., Fitzgibbon, Q. P., Hartmann, K., and Semmens, J. M. (2017). Exposure to seismic air gun signals causes physiological harm and alters behavior in the scallop *Pecten fumatus*. *Proceedings of the National Academy of Sciences*, 114(40), E8537-E8546.
- Day, R. D., McCauley, R. D., Fitzgibbon, Q. P., Hartmann, K., and Semmens, J. M. (2016). Assessing the impact of marine seismic surveys on southeast Australian scallop and lobster fisheries. *Fisheries Research and Development Corporation*. Report 2012/008.
- DCCEEW (2023). Guidance – Key environmental factors for offshore windfarm environmental impact assessment under the Environment Protection and Biodiversity Conservation Act 1999, Department of Climate Change, Energy, the Environment and Water, Canberra, July.
- de Jong, K., Forland, T. N., Amorim, M. C. P., Rieucou, G., Slabbekoorn, H., and Sivle, L. D. (2020). Predicting the effects of anthropogenic noise on fish reproduction. *Reviews in Fish Biology and Fisheries*, 30(2), 245-268.
- De Soto, N. A., Delorme, N., Atkins, J., Howard, S., Williams, J., and Johnson, M. (2013). Anthropogenic noise causes body malformations and delays development in marine larvae. *Scientific reports*, 3(1), 2831.
- Degraer, S., Brabant, R., Rumes, B. and Vigin, L. (2023). Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Progressive Insights in Changing Species Distribution Patterns Informing Marine Management. *Memoirs on the Marine Environment*. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, *Marine Ecology and Management*, 115 pp.
- Department of Housing, Local Government and Heritage. (2024). *Ireland's marine strategy: Part 1 – Article 8, 9 and 10 report*. Government of Ireland.
- Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities, L 327, 22.12.2000, pp. 1–73
- Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds. Official Journal of the European Union, L 20, 26.1.2010, pp. 7–25.
- European Environment Agency (EEA). (2020). Multiple pressures and their combined effects in Europe's seas. Retrieved from: <https://www.eea.europa.eu/en/analysis/publications/multiple-pressures-and-their-combined-effects-in-europes-seas>
- El-Dairi, R., Outinen, O. and Kankaanpää, H. (2024). Anthropogenic underwater noise: A review on physiological and molecular responses of marine biota. *Marine Pollution Bulletin*, 199, p.115978.
- Environmental Protection Authority (2021), Technical Guidance – Environmental impact assessment of marine dredging proposals, EPA, Western Australia.
- Fewtrell, J. L., and McCauley, R. D. (2012). Impact of air gun noise on the behaviour of marine fish and squid. *Marine pollution bulletin*, 64(5), 984-993.
- Flávio, H., Seitz, R., Eggleston, D., Svendsen, J., and Stottrup, J. (2023). Hard-bottom habitats support commercially important fish species: a systematic review for the North Atlantic Ocean and Baltic Sea. *PeerJ*, 11:e14681.
- Foden, J., Rogers, S., and Jones, A. (2011). Human pressures on UK seabed habitats: a cumulative impact assessment. *Marine Ecology Progress Series*, 438, 33-47.
- Franco, A., Smyth, K., Thomson, S. (2022). Developing Essential Fish Habitat maps for fish and shellfish species in Scotland. Report to the Scottish Government, December 2022.
- Galparsoro, I., Menchaca, I., Garmendia, J., Borja, Á., Maldonado, A., Iglesias, G., and Bald, J. (2022). Reviewing the ecological impacts of offshore wind farms. *npj Ocean Sustainability*, 1, 1.
- Gates, A., and Jones, D. (2012). Recovery of benthic megafauna from anthropogenic disturbance at a hydrocarbon drilling well (380 m depth in the Norwegian Sea). *PLoS ONE*, 7, 10.
- Guerra, A., González, A. F., and Rocha, F. (2004). A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. *ICES CM*, 200 (2004), p. 29
- Halpern, B., Walbridge, S., Selkoe, K., Kappel, C., Micheli, F., D'Agrosa, C., Bruno, J., Casey, K., Ebert, C., Fox, H., Fujita, R., Heinemann, D., Lenihan, H., Madin, E., Perry, M., Selig, E., Spalding, M., Steneck, R., and Watson, R. (2008). A global map of human impact on marine ecosystems. *Science*. 319(5865), 948-52.
- Hassel, A., Knutsen, T., Dalen, J., Skaar, K., Løkkeborg, S., Misund, O.A., Østensen, Ø., Fonn, M. and Haugland, E.K. (2004). Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). *ICES Journal of Marine Science*, 61(7), 1165-1173.
- Hawkins, A.D. and Popper, A.N. (2017). A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. *ICES Journal of Marine Science*, 74(3), pp.635-651.
- Hawkins, A.D. and Popper, A.N. (2018). Directional hearing and sound source localization by fishes. *The Journal of the Acoustical Society of America*, 144(6), pp.3329-3350.
- Hubert, J., Campbell, J. A., and Slabbekoorn, H. (2020). Effects of seismic airgun playbacks on swimming patterns and behavioural states of Atlantic cod in a net pen. *Marine Pollution Bulletin*, 160, 111680.
- Hawkins, A.D. and Picciulin, M. (2019). The importance of underwater sounds to gadoid fishes. *The Journal of the Acoustical Society of America*, 146(5), pp.3536-3551.

- International Society for Soil Mechanics and Geotechnical Engineering. (2005). Geotechnical and Geophysical investigations for offshore and nearshore developments. Technical Committee 1, International Society for Soil Mechanics and Geotechnical Engineering, September 2005.
- JNCC, Natural England and Countryside Council for Wales. (2010). The protection of marine European Protected Species from injury and disturbance: Guidance for the marine area in England and Wales and the UK offshore marine area.
- Joint Nature Conservation Committee (JNCC). (2017). JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys. Peterborough: JNCC.
- Jones, D., Hudson, I., and Bett, B. (2006). Effects of physical disturbance on the cold-water megafaunal communities of the Faroe-Shetland Channel. *Marine Ecology Progress Series*, 319, 43-54.
- Kaiser, M., Clarke, K., Hihz, H., Austen, M., Somerfield, P., Karakassis, I. (2006). Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series*, 311, 1-14.
- Kenny, A., and Rees, H. (1996). The effects of marine gravel extraction on the macrobenthos: Results 2 years post-dredging. *Marine Pollution Bulletin*, 32, 615-622.
- King, J.L., Marnell, F., Kingston, N., Rosell, R., Boylan, P., Caffrey, J.M., FitzPatrick, Ú., Gargan, P.G., Kelly, F.L., O'Grady, M.F., Poole, R., Roche, W.K. and Cassidy, D. (2011) Ireland Red List No. 5: Amphibians, Reptiles & Freshwater Fish. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.
- Kjelland, M., Woodley, C., Swannack, T. (2015). A review of the potential effects of suspended sediment on fishes: potential dredging-related physiological, behavioural, and transgenerational implications. *Environment Systems and Decisions*, 35, 334-350.
- Korpinen, S., Laamanen, L., Bergstrom, L., Nurmi, M., Andersen, J., Haapaniemi, J., Harvey, T., Murray, C., Peterlin, M., Kallenbach, E., Klančnik, K., Stein, U., Tunesi, L., Vaughan, D., Reker, J. (2021). Combined effects of human pressures on Europe's marine ecosystems. *Ambio*, 50, 1325-1336.
- La Bella, G., Cannata, S., Froglià, C., Modica, A., Ratti, S., and Rivas, G. (1996). First assessment of effects of air-gun seismic shooting on marine resources in the central Adriatic Sea. In *SPE International Conference and Exhibition on Health, Safety, Environment, and Sustainability?* SPE-35782.
- Ladich, F. (2019). Ecology of sound communication in fishes. *Fish and fisheries*, 20(3), pp.552-563.
- Lagardère, J. P. (1982). Effects of noise on growth and reproduction of Crangon crangon in rearing tanks. *Marine Biology*, 71(2), 177-185.
- Last, S., Hendrick, V., Beveridge, C., and Davies, A. (2011). Measuring the effects of suspended particulate matter and smothering on the behaviour, growth and survival of key species found in areas associated with aggregate dredging. Report for the Marine Aggregate Levy Sustainability Fund, Project MEPF 08/P76, 69.
- Løkkeborg, S., Ona, E., Vold, A., and Salthaug, A. (2012). Sounds from seismic air guns: gear-and species-specific effects on catch rates and fish distribution. *Canadian Journal of Fisheries and Aquatic Sciences*, 69(8), 1278-1291.
- Magris, R., and Ban, N. (2019). A meta-analysis reveals global patterns of sediment effects on marine biodiversity. *Global Ecology and Biogeography*, 00, 1-20.
- Marine Institute and Bord Iascaigh Mhara 2024. Shellfish Stocks and Fisheries Review 2024. Available at: <https://oar.marine.ie/entities/publication/6bc40f08-d4f3-4831-b4da-257ad96146fb> (Accessed 1 April 2026).
- Maritime Area Planning Act 2021 (No. 50 of 2021). Electronic Irish Statute Book.
- Marshall, C., and Wilson, E. (2008). Pecten maximus Great scallop. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom.
- McCauley, R. D., Fewtrell, J., and Popper, A. N. (2003). High intensity anthropogenic sound damages fish ears. *The Journal of the Acoustical Society of America*, 113(1), 638-642.
- McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M.N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J. and McCabe, K. (2000). Marine seismic surveys – a study of environmental implications. *Appea Journal*, 40(1), 692-708.
- McQueen, K., Sivle, L.D., Forland, T.N., Meager, J.J., Skjæraasen, J.E., Olsen, E.M., Karlsen, Ø., Kvasdheim, P.H. and de Jong, K. (2024). Continuous sound from a marine vibrator causes behavioural responses of free-ranging, spawning Atlantic cod (Gadus morhua). *Environmental Pollution*, 344, 123322.
- McQueen, K., Meager, J.J., Nyqvist, D., Skjæraasen, J.E., Olsen, E.M., Karlsen, Ø., Kvasdheim, P.H., Handegard, N.O., Forland, T.N. and Sivle, L.D. (2022). Spawning Atlantic cod (Gadus morhua L.) exposed to noise from seismic airguns do not abandon their spawning site. *ICES Journal of Marine Science*, 79(10), 2697-2708.
- Meekan, M.G., Speed, C.W., McCauley, R.D., Fisher, R., Birt, M.J., Currey-Randall, L.M., Semmens, J.M., Newman, S.J., Cure, K., Stowar, M. and Vaughan, B. (2021). A large-scale experiment finds no evidence that a seismic survey impacts a demersal fish fauna. *Proceedings of the National Academy of Sciences*, 118(30), e2100869118.
- Mooney, T.A., Hanlon, R.T., Christensen-Dalsgaard, J., Madsen, P.T., Ketten, D.R. and Nachtigall, P.E. (2010). Sound detection by the longfin squid (Loligo pealeii) studied with auditory evoked potentials: sensitivity to low-frequency particle motion and not pressure. *Journal of Experimental Biology*, 213(21), pp.3748-3759.
- Moriyasu, M., Allain, R., Benhalima, K., and Claytor, R. (2004). *Effects of seismic and marine noise on invertebrates: A literature review*. Department of Fisheries and Oceans. Canadian Science Advisory Secretariat. Research document. 2004/126, 50.
- Mueller-Blenkle, C., Jones, E., Reid, D., Lüdemann, K., Kafemann, R., and Elepfandt, A. (2008). Reactions of cod Gadus morhua to low-frequency sound resembling offshore wind turbine noise emissions. *Bioacoustics*, 17(1-3), 207-209.
- National Marine Planning Framework (Department of Housing, Local Government and Heritage, 2021)

- Neo, Y. Y., Hubert, J., Bolle, L. J., Winter, H. V., and Slabbekoorn, H. (2018). European seabass respond more strongly to noise exposure at night and habituate over repeated trials of sound exposure. *Environmental pollution*, 239, 367-374.
- Newell, R., Seiderer, L., & Hitchcock, D. (1998). The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology: An Annual Review*, 36, 127-178.
- Nichols, T. A., Anderson, T. W., and Širović, A. (2015). Intermittent noise induces physiological stress in a coastal marine fish. *PLoS One*, 10(9), e0139157.
- NMFS. (2025). Biological and Conference Opinion on Bureau of Ocean Energy Management and Bureau of Safety and Environmental Enforcement's Oil and Gas Program Activities in the Gulf of America.
- O'Leary, C., Brett, A. and Poole, R. (2022). An identification guide to migratory diadromous fish at sea. *DiadSea Booklet*.
- OSPAR Commission. (2016). OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise (2016 update).
- OSPAR Commission. (2021). OSPAR Technical Report on Current Understanding of Deep Seabed Mining: Resources, Technology, Potential Impacts and Regulation along with the Current Global Demand for Minerals. OSPAR, London (Publication Number 790/2021).
- Offshore Wind Programme Board. (2015). Overview of geophysical and geotechnical marine surveys for offshore wind transmission cables in the UK. Retrieved from: <https://cms.ore.catapult.org.uk/wp-content/uploads/2018/02/Overview-of-geophysical-and-geotechnical-marine-surveys-for-offshore-wind-transmission-cables-in-the-UK.pdf>
- Parry, G. D., Heislors, S., Werner, G. F., Asplin, M. D., and Gason, A. (2002). Assessment of environmental effects of seismic testing on scallop fisheries in Bass Strait. *Marine and Freshwater Resources Institute Report*, (50), 32.
- Parsons, M.J., Barneche, D.R., Speed, C.W., McCauley, R.D., Day, R.D., Dang, C., Fisher, R., Gholipour-Kanani, H., Newman, S.J., Semmens, J.M. and Meekan, M.G. (2024). A large-scale experiment finds no consistent evidence of change in mortality or commercial productivity in silverlip pearl oysters (*Pinctada maxima*) exposed to a seismic source survey. *Marine Pollution Bulletin*, 199, 115480.
- Payne, J. F., Andrews, C. A., Fancey, L. L., Cook, A. L., and Christian, J. R. (2007). Pilot Study on the Effects of Seismic Air Gun Noise on Lobster (*Homarus americanus*). St. John's Canadian Technical Report of Fisheries and Aquatic Sciences No. 2712.
- Pearson, W. H., Skalski, J. R., and Malme, C. I. (1992). Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Sciences*, 49(7), 1343-1356.
- Pine, M. K., Nikolich, K., Martin, B., Morris, C., and Juanes, F. (2020). Assessing auditory masking for management of underwater anthropogenic noise. *The Journal of the Acoustical Society of America*, 147(5), 3408-3417.
- Pinheiro, M., Oliveira, A., Barros, S., alves, N., Raimundo, J., Caetano, M., Coimbra, J., Neuparth, T., Santos, M. (2021). Functional, biochemical and molecular impact of sediment plumes from deep-sea mining on *Mytilus galloprovincialis* under hyperbaric conditions. *Environmental Research*, 195, 110753.
- Planning and Development Act 2000 (No. 30 of 2000). Electronic Irish Statute Book (eISB).
- Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D., Bartol, S., Carlson, Th., Coombs, S., Ellison, W. T., Gentry, R., Halvorsen, M. B., Lokkeborg, S., Rogers, P., Southall, B. L., Zeddies, D. G. and Tavalga, W. N. (2014). 'ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles', A Technical Report prepared by ANSI Accredited Standards Committee S3/SC1 and registered with ANSI. Springer and ASA Press, Cham, Switzerland.
- Popper, A.N. and Hastings, M.C. (2009). The effects of anthropogenic sources of sound on fishes. *Journal of fish biology*, 75(3), pp.455-489.
- Popper, A.N., Halvorsen, M.B., Kane, A., Miller, D.L., Smith, M.E., Song, J., Stein, P. and Wysocki, L.E. (2007). The effects of high-intensity, low-frequency active sonar on rainbow trout. *The Journal of the Acoustical Society of America*, 122(1), 623-635.
- Popper, A. N., Ramcharitar, J., & Campana, S. E. (2005). Why otoliths? Insights from inner ear physiology and fisheries biology. *Marine and freshwater Research*, 56(5), 497-504.
- Przeslawski, R., Bruce, B., Carroll, A., Anderson, J., Bradford, R., Durrant, A., Edmunds, M., Foster, S., Huang, Z., Hurt, L., Lansdell, M., Lee, K., Lees, C., Nichols, P. and Williams, S. (2016). Marine Seismic Survey Impacts on Fish and Invertebrates: Final Report for the Gippsland Marine Environmental Monitoring Project.
- Przeslawski, R., Huang, Z., Anderson, J., Carroll, A. G., Edmunds, M., Hurt, L., and Williams, S. (2018). Multiple field-based methods to assess the potential impacts of seismic surveys on scallops. *Marine pollution bulletin*, 129(2), 750-761.
- Regnault, N., and Lagardere, J. P. (1983). Effects of ambient noise on the metabolic level of Crangon crangon (Decapoda, Natantia). *Marine Ecology Progress Series*, 11, 71-78.
- Ruppel, C. D., Weber, T. C., Staatterman, E. R., Labak, S. J., and Hart, P. E. (2022). Categorizing active marine acoustic sources based on their potential to affect marine animals. *Journal of Marine Science and Engineering*, 10(9), 1278.
- Santulli, A., Modica, A., Messina, C., Ceffa, L., Curatolo, A., Rivas, G., Fabi, G. and D'amelio, V. (1999). Biochemical responses of European sea bass (*Dicentrarchus labrax* L.) to the stress induced by off shore experimental seismic prospecting. *Marine Pollution Bulletin*, 38(12), 1105-1114.
- Sierra-Flores, R., Atack, T., Migaud, H., and Davie, A. (2015). Stress response to anthropogenic noise in Atlantic cod *Gadus morhua* L. *Aquacultural engineering*, 67, 67-76.
- Simpson, S. D., Radford, A. N., Nedelec, S. L., Ferrari, M. C., Chivers, D. P., McCormick, M. I., and Meekan, M. G. (2016). Anthropogenic noise increases fish mortality by predation. *Nature communications*, 7(1), 10544.
- Slater, M., Fricke, E., Weiss, M., Rebelein, A., Bögner, M., Preece, M., and Radford, C. (2020). The impact of

- aquaculture soundscapes on whiteleg shrimp *Litopenaeus vannamei* and Atlantic salmon *Salmo salar*. *Aquaculture Environment Interactions*, 12, 167-177.
- Solan, M., Hauton, C., Godbold, J. A., Wood, C. L., Leighton, T. G., and White, P. (2016). Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties. *Scientific reports*, 6(1), 20540.
- Solé, M., Lenoir, M., Durfort, M., López-Bejar, M., Lombarte, A., Van der Schaar, M., and André, M. (2013). Does exposure to noise from human activities compromise sensory information from cephalopod statocysts?. *Deep Sea Research Part II: Topical Studies in Oceanography*, 95, 160-181.
- Stelzenmüller, V., Ellis, J., and Rogers, S. (2010). Towards a spatially explicit risk assessment for marine management: Assessing the vulnerability of fish to aggregate extraction. *Biological Conservation*, 143(2), 230–238.
- Tidau, S., and Briffa, M. (2019). Distracted decision makers: ship noise and predation risk change shell choice in hermit crabs. *Behavioral Ecology*, 30(4), 1157-1167.
- Tillin, H., Houghton, A., Saunders, J., Drabble, R., and Hull, S. (2011). Direct and indirect impacts of marine aggregate dredging. Marine Aggregate Levy Sustainability Fund (MALSF) Science Monograph Series No 1. MEPF 10/P144. 41pp.
- Utne-Palm, A. (2002). Visual feeding of fish in a turbid environment: Physical and behavioural. *Marine and Freshwater and Physiology*, 35(1-2), 111-128.
- van der Knaap, I., Reubens, J., Thomas, L., Ainslie, M.A., Winter, H.V., Hubert, J., Martin, B. and Slabbekoorn, H., 2021. (2021). Effects of a seismic survey on movement of free-ranging Atlantic cod. *Current Biology*, 31(7), 1555-1562.
- Van Hoey, G., Bastardie, F., Birchenough, S., De Backer, A., Gill, A., de Koning, S., Hodgson, S., Mangi Chai, S., Steenbergen, J., Termeer, E., van den Burg, S., Hintzen, N. (2021). Overview of the effects of offshore wind farms on fisheries and aquaculture, Publications Office of the European Union, Luxembourg, p. 99.
- Wale, M. A., Briers, R. A., Hartl, M. G., Bryson, D., and Diele, K. (2019). From DNA to ecological performance: effects of anthropogenic noise on a reef-building mussel. *Science of the Total Environment*, 689, 126-132.
- Wale, M. A., Simpson, S. D., and Radford, A. N. (2013). Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. *Biology letters*, 9(2), 20121194.
- Wardle, C. S., Carter, T. J., Urquhart, G. G., Johnstone, A. D. F., Ziolkowski, A. M., Hampson, G., and Mackie, D. (2001). Effects of seismic air guns on marine fish. *Continental shelf research*, 21(8-10), 1005-1027.
- Wenger, A., Harvey, E., Wilson, S., Rawson, C., Newman, S., Clarke, D., Saunders, B., Browne, N., Travers, M., Mcilwain, J., Erfteimeijer, P., Hobbs, J-P., Mclean, D., Depczynski, M., and Evans, R. (2017). A critical analysis of the direct effects of dredging on fish. *Fish and Fisheries*, 18(4), 613–639.
- Wilber, D., and Clarke, D. (2001): Biological Effects of Suspended Sediments: A Review of Suspended Sediment Impacts on Fish and Shellfish with Relation to Dredging Activities in Estuaries, *North American Journal of Fisheries Management*, 21, 4, 855-875
- West, V., Maher, E. and Alexander, D. (2024). Reef Habitat in Irish Intertidal and Nearshore Waters. Irish Wildlife Manuals, No. 150. National Parks and Wildlife Service, Department of Housing, Local Government and Heritage, Ireland.

## 9. Appendices

### 9.1. Appendix I

#### 9.1.1. Systematic Literature Review methodology

The search terms employed in the systematic literature review were derived from project scoping, encompassing survey-related descriptors (for example, "geotechnical", "dredging", "borehole"), impact descriptors (for example, "smothering", "physical disturbance", "habitat alteration"), species groups (fish, shellfish, crustaceans) and species common names from Table 3.1 and geographic qualifiers (e.g. Irish Sea, Celtic Sea). These terms were refined into 21 targeted search string combinations, eliminating duplication and maximising coverage of ecologically relevant interactions. Literature searches were executed primarily via Google Scholar and Google Search, spanning publications from 1980 to 2026 in English, with an initial preference for review articles and peer-reviewed literature, though grey literature was also reviewed.

Screening yielded a total of 60 sources, categorised by priority according to methodological rigour, relevance to geotechnical activities or analogous pressures (such as physical disturbance, habitat alteration or removal, smothering, and sediment resuspension), and species specificity. Tier 1 resources comprised 33 peer-reviewed papers representing the highest relevance, robustness and value, addressing direct impacts or close analogues on species and impact types. Tier 2 resources included 11 peer-reviewed papers of medium priority, integrating peer-reviewed and grey literature on less relevant but still somewhat analogous impacts. Tier 3 encompassed 16 supporting sources of lowest priority, predominantly grey literature and technical reports of least relevance to the impact types and difficulty in comparing to our impact types and target species.

#### 9.1.2. Search terms used for identifying international best practice documents

1. ("international guidelines" OR "best practice" OR "OSPAR" OR "PIANC" OR "BOEM" OR "ICES") AND ("fish" OR "crustaceans" OR "molluscs" OR "elasmobranchs" OR "demersal fish" OR "Nephrops" OR "Norway lobster") AND ("smothering" OR "physical disturbance" OR "habitat alteration" OR "habitat loss" OR "sediment disturbance") AND ("dredging" OR "geotechnical" OR "Geotech" OR "site investigation" OR "borehole" OR "vibrocorer" OR "CPT" OR "trawling")
2. ("guidelines" OR "best practice") AND ("benthic impacts" OR "smothering" OR "burial" OR "sediment plume") AND ("dredging" OR "geotechnical" OR "trawling") AND ("fish" OR "shellfish" OR "crustacean" OR "mollusc" OR "elasmobranch")
3. "OSPAR" OR "PIANC" OR "BOEM" AND "geotechnical survey" OR "site investigation" AND ("marine ecology" OR "fish" OR "benthic invertebrates" OR "smothering" OR "disturbance")
4. ("best practice" OR "guidelines" OR "framework") AND ("offshore activities" OR "wind" OR "oil gas" OR "dredging" OR "geotechnical") AND ("fish" OR "shellfish" OR "crustaceans" OR "molluscs" OR "elasmobranchs") AND ("US" OR "USA" OR "United States" OR "Canada" OR "Norway" OR "China" OR "Australia" OR "New Zealand").

## 9.2. Appendix II

**Table 9.1. A summary of impulsive noise studies used within the Impacts from Underwater Noise section (4.1.1). SPL refers to sound pressure level, SEL refers to sound exposure level and SVL refers to sound velocity level. Grouping refers to anatomical grouping based on Popper *et al.* (2014).**

Reference	Study species	Grouping	Sound features	Effect	Location
Christian <i>et al.</i> , 2003	Snow crab ( <i>Chionoecetes opilio</i> ) eggs	4 - Larvae and eggs	<ul style="list-style-type: none"> <li>Air gun</li> <li>197 - 237 dB re 1 <math>\mu</math>Pa</li> <li>175 - 187 dB re 1 <math>\mu</math>Pa<sup>2</sup>/Hz</li> </ul>	Mortality	Canada
Day <i>et al.</i> , 2017	Scallops ( <i>Pecten fumatus</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>191 - 213 dB re 1 <math>\mu</math>Pa</li> <li>Cumulative SEL 189 - 197 dB re 1 <math>\mu</math>Pa</li> </ul>	Mortality	Tasmania
Guerra <i>et al.</i> , 2004	Giant squid ( <i>Architeuthis dux</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>200 dB re 1 <math>\mu</math>Pa</li> <li>&lt; 100 Hz</li> </ul>	Mortality	Northern Spain
McCauley <i>et al.</i> , 2003	Pink snapper ( <i>Pagrus auratus</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>203.6 - 222.6 dB re 1 <math>\mu</math>Pa</li> <li>&lt;1000 Hz</li> </ul>	Injury	Western Australia
De Soto <i>et al.</i> , 2013	New Zealand Scallop larvae ( <i>Pecten novaezelandiae</i> )	4 - Larvae and eggs	<ul style="list-style-type: none"> <li>Tank impulsive noise playback</li> <li>SEL 160 - 165 dB re 1 <math>\mu</math>Pa<sup>2</sup>s</li> <li>40 - 200 Hz</li> </ul>	Injury	New Zealand
Day <i>et al.</i> , 2016	Southern rock lobster ( <i>Jasus edwardsii</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>SEL 209 - 212 dB re 1 <math>\mu</math>Pa</li> <li>Cumulative SEL 186 - 205 dB re 1 <math>\mu</math>Pa<sup>2</sup>s</li> </ul>	Injury	Tasmania
André <i>et al.</i> , 2011	Cephalopods ( <i>Loligo vulgaris</i> , <i>Sepia officinalis</i> , <i>Octopus vulgaris</i> , and <i>Illex coindetii</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank impulsive noise playback</li> <li>157 - 175 dB re 1 <math>\mu</math>Pa</li> <li>50 - 400 Hz</li> </ul>	Injury	Tank study, Spain
Solé <i>et al.</i> , 2013	Cephalopods ( <i>Loligo vulgaris</i> , <i>Sepia officinalis</i> , <i>Octopus vulgaris</i> , and <i>Illex coindetii</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank impulsive noise playback</li> <li>157 - 175 dB re 1 <math>\mu</math>Pa</li> <li>50 - 400 Hz</li> </ul>	Injury	Tank study, Spain
Santulli <i>et al.</i> , 1999	European seabass ( <i>Dicentrarchus labrax</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>~ 220 dB re 1 <math>\mu</math>Pa</li> <li>&lt; 100 Hz</li> </ul>	Physiological changes	Italy
Dauidsen <i>et al.</i> , 2019	Atlantic cod ( <i>Gadus morhua</i> ), Saithe ( <i>Pollachius virens</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>SEL 105 - 158 dB re 1 <math>\mu</math>Pa<sup>2</sup>s</li> <li>Cumulative SEL 105 - 175 dB re 1 <math>\mu</math>Pa<sup>2</sup>s</li> </ul>	Physiological changes (Atlantic cod) Behavioural changes (Atlantic cod and Saithe)	Norway

Reference	Study species	Grouping	Sound features	Effect	Location
Payne <i>et al.</i> , 2007	American lobster ( <i>Homarus americanus</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>202-230 dB re 1 <math>\mu</math>Pa</li> <li>Density 187 dB re 1 <math>\mu</math> Pa<sup>2</sup>/Hz</li> <li>18.5 - 31 Hz</li> </ul>	Physiological changes Behavioural changes	Canada
La Bella <i>et al.</i> , 1996; Moriyasu <i>et al.</i> , 2004	Golden carpet shell ( <i>Polittapes aureus</i> ) Purple dye murex ( <i>Bolinus brandaris</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>210 dB re 1 <math>\mu</math>Pa</li> </ul>	Physiological changes (Golden carpet shell) Behavioural changes (Purple dye murex)	Adriatic Sea
Hassel <i>et al.</i> , 2004	Lesser sandeel ( <i>Ammodytes marinus</i> )	1 - Lack a swim bladder	<ul style="list-style-type: none"> <li>Air gun</li> <li>256.1 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Southeastern North Sea
Løkkeborg <i>et al.</i> , 2012	Redfish ( <i>Sebastes norvegicus</i> ), haddock ( <i>Melanogrammus aeglefinus</i> ), saithe ( <i>Pollachius virens</i> ) and ling ( <i>Molva molva</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>140 - 191 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Norway
Løkkeborg <i>et al.</i> , 2012	Greenland halibut ( <i>Reinhardtius hippoglossoides</i> )	1 - Lack a swim bladder	<ul style="list-style-type: none"> <li>Air gun</li> <li>140 - 191 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Norway
Neo <i>et al.</i> , 2018	European seabass ( <i>Dicentrarchus labrax</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Impulsive brown noise</li> <li>SPL 180 - 192 dB re 1 <math>\mu</math>Pa</li> <li>SVL 124 - 125 dB re 1 nm/s</li> <li>200 - 1000Hz</li> </ul>	Behavioural changes	North Sea, Netherlands
van der Knaap <i>et al.</i> , 2021	Atlantic cod ( <i>Gadus morhua</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>123 dB re 1 <math>\mu</math>Pa</li> <li>Cumulative SEL 186.3 dB re 1 <math>\mu</math>Pa</li> <li>40 - 400 Hz</li> </ul>	Behavioural changes	Belwind offshore wind farm, southern North Sea
Hubert <i>et al.</i> , 2020	Atlantic cod ( <i>Gadus morhua</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Tank playback of air guns</li> <li>99 - 174 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Netherlands
Pearson <i>et al.</i> , 1992	Rockfish ( <i>Sebastes</i> spp.)	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>Source 223 dB re 1 <math>\mu</math>Pa</li> <li>Received 137 - 207 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	North America
Wardle <i>et al.</i> , 2001	Saithe ( <i>Pollachius virens</i> ), Atlantic cod ( <i>Gadus morhua</i> ), pollock ( <i>Pollachius pollachius</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>195 - 218 dB re 1 <math>\mu</math>Pa</li> <li>80 - 120 Hz</li> </ul>	Behavioural changes	Scotland
Wardle <i>et al.</i> , 2001	Mackerel ( <i>Scomber scombrus</i> )	1 - Lack a swim bladder	<ul style="list-style-type: none"> <li>Air gun</li> <li>195 - 218 dB re 1 <math>\mu</math>Pa</li> <li>80 - 120 Hz</li> </ul>	Behavioural changes	Scotland
Fewtrell and McCauley, 2012	Trevally ( <i>Pseudocaranx dentex</i> ), pink snapper ( <i>Pagrus auratus</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>Source 192 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Western Australia

Reference	Study species	Grouping	Sound features	Effect	Location
			<ul style="list-style-type: none"> <li>Received 120 and 184 dB re 1 <math>\mu</math>Pa</li> </ul>		
Fewtrell and McCauley, 2012	Squid ( <i>Sepioteuthis australis</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>Source 192 dB re 1 <math>\mu</math>Pa</li> <li>Received 120 and 184 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Western Australia
Boeger <i>et al.</i> , 2006	Snappers ( <i>Lutjanus synagris</i> and <i>Lutjanus apodus</i> ) and Atlantic spadefish ( <i>Chaetodipterus faber</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>196 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Brazil
McCauley <i>et al.</i> , 2000	Squid ( <i>Sepioteuthis australis</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>156 - 174 dB re 1 <math>\mu</math>Pa</li> <li>&lt; 200 Hz</li> </ul>	Behavioural changes	Western Australia
Meekan <i>et al.</i> , 2021	Tropical demersal fish species	Assemblage – N/A	<ul style="list-style-type: none"> <li>Air gun</li> <li>SEL 231 – 247 dB re 1 <math>\mu</math>Pa</li> <li>228 dB re 1 <math>\mu</math>Pa<sup>2</sup>/m<sup>2</sup>/s</li> <li>&lt; 1000 Hz</li> </ul>	No effect	Northwest Australia
McQueen <i>et al.</i> , 2022	Atlantic cod ( <i>Gadus morhua</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>115 - 145 dB re 1 <math>\mu</math>Pa<sup>2</sup>s</li> <li>&lt; 100 Hz</li> </ul>	No effect	Norway
Pine <i>et al.</i> , 2020	Atlantic cod ( <i>Gadus morhua</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Air gun</li> <li>127 dB re 1 <math>\mu</math>Pa</li> <li>22 - 88 Hz</li> </ul>	No effect	Canada
Parsons <i>et al.</i> , 2024	Silverlip Pearl Oyster ( <i>Pinctada maxima</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>252 dB re 1 <math>\mu</math>Pa</li> <li>SEL 228 dB re 1 <math>\mu</math>Pa<sup>2</sup>/m<sup>2</sup>/s</li> <li>&lt; 1000 Hz</li> </ul>	No effect	Northwest Australia
Przeslawski <i>et al.</i> , 2018	Australian scallop ( <i>Pecten fumatus</i> ), Austral scallop ( <i>Mimachlamys asperrima</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>146 - 170 dB re 1 <math>\mu</math>Pa<sup>2</sup>s</li> <li>40 - 80 Hz</li> </ul>	No effect	Australia
Parry <i>et al.</i> , 2002	Australian scallop ( <i>Pecten fumatus</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>211 dB re 1 <math>\mu</math>Pa</li> <li>50 Hz</li> </ul>	No effect	Australia
Parry <i>et al.</i> , 2002	Bivalve larvae	4 - Larvae and eggs	<ul style="list-style-type: none"> <li>Air gun</li> <li>211 dB re 1 <math>\mu</math>Pa</li> <li>50 Hz</li> </ul>	No effect	Australia
Andrighetto-Filho <i>et al.</i> , 2005	Various shrimp species	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>196 dB re 1 <math>\mu</math>Pa</li> </ul>	No effect	Brazil
Courtenay <i>et al.</i> , 2009	Snow crab ( <i>Chionoecetes opilio</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Air gun</li> <li>SEL 167 dB re 1 <math>\mu</math>Pa</li> <li>125 – 200 Hz</li> </ul>	No effect	Canada

**Table 9.2. A summary of continuous noise studies used within the Impacts from Underwater Noise section (4.1.2). SPL refers to sound pressure level, SEL refers to sound exposure level and SVL refers to sound velocity level. Grouping refers to anatomical grouping based on Popper *et al.* (2014).**

Reference	Receiver	Grouping	Sound features	Effect	Location
Buscaino <i>et al.</i> , 2010	European sea bass ( <i>Dicentrarchus labrax</i> ) and gilthead sea bream ( <i>Sparus aurata</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Tank playback</li> <li>150 dB re 1 <math>\mu</math>Pa</li> <li>0.1 – kHz</li> </ul>	Physiological changes	Tank study, Italy
Celi <i>et al.</i> , 2016	Gilthead sea bream ( <i>Sparus aurata</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Tank playback</li> <li>SPL 128 dB re 1 <math>\mu</math>Pa</li> <li>62.5 - 16,000 Hz</li> </ul>	Physiological changes	Tank study, Italy
Anderson <i>et al.</i> , 2011	Lined seahorse ( <i>Hippocampus erectus</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Tank playback</li> <li>54.6 - 123.9 dB re 1 <math>\mu</math>Pa</li> <li>&lt; 1000 Hz</li> </ul>	Physiological changes Behavioural changes	Tank study, North America
Sierra-Flores <i>et al.</i> , 2015	Atlantic cod ( <i>Gadus morhua</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Tank playback</li> <li>108.7 - 110.3 dB re 1 <math>\mu</math>Pa</li> <li>100 to 1000 Hz</li> </ul>	Physiological changes	Tank study, Scotland
Wale <i>et al.</i> , 2013	Shore crabs ( <i>Carcinus maenas</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank playback</li> <li>148 - 155 dB re 1 <math>\mu</math>Pa</li> </ul>	Physiological changes	Tank study, England
Regnault and Lagardère, 1983	Brown shrimp ( <i>Crangon crangon</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank playback</li> <li>105 dB re 1 <math>\mu</math>Pa</li> </ul>	Physiological changes	Tank study, France
Lagardère, 1982	Brown shrimp ( <i>Crangon crangon</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank playback</li> <li>30 dB</li> <li>25 - 400 Hz</li> </ul>	Physiological changes Behavioural changes	Tank study, France
Celi <i>et al.</i> , 2015	European spiny lobster ( <i>Palinurus elephas</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank playback</li> <li>120 dB re 1 <math>\mu</math>Pa</li> </ul>	Physiological changes	Tank study, Italy
Wale <i>et al.</i> , 2019	Blue mussel ( <i>Mytilus edulis</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank playback</li> <li>150–155 dB re 1 <math>\mu</math>Pa<sup>2</sup>Hz<sup>-1</sup></li> </ul>	Physiological changes Behavioural changes	Tank study, Scotland
Simpson <i>et al.</i> , 2016	Damselfish ( <i>Pomacentrus amboinensis</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Tank playback</li> <li>50 - 130 db re 1 <math>\mu</math>Pa<sup>2</sup>Hz<sup>-1</sup></li> <li>&lt; 3000 Hz</li> </ul>	Behavioural changes	Tank and field study, Australia
McQueen <i>et al.</i> , 2024	Atlantic cod ( <i>Gadus morhua</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Marine vibrator</li> <li>SEL 115 -145 dB re 1 <math>\mu</math>Pa<sup>2</sup>s</li> <li>115 - 150 dB re 1 <math>\mu</math>Pa</li> <li>3 - 150 Hz</li> </ul>	Behavioural changes	Norway
Mueller-Blenkle <i>et al.</i> , 2008	Atlantic cod ( <i>Gadus morhua</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>Tank playback</li> <li>130 - 140 dB re 1 <math>\mu</math>Pa</li> <li>25, 60, 90, 125, 250 Hz</li> </ul>	Behavioural changes	Tank study, Aberdeen
Solan <i>et al.</i> , 2016	Nephrops ( <i>Nephrops norvegicus</i> ), Clam ( <i>Ruditapes philippinarum</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>Tank playback</li> <li>135 – 140 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Tank study, Southampton

Reference	Receiver	Grouping	Sound features	Effect	Location
Charifi <i>et al.</i> , 2017	Pacific oyster ( <i>Magallana gigas</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>• Tank playback</li> <li>• 100 - 158 dB rm</li> <li>• 10 to &lt; 1000 Hz</li> </ul>	Behavioural changes	Tank study, France
Birch <i>et al.</i> , 2025	Shore crabs ( <i>Hemigrapsus oregonensis</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>• Tank playback</li> <li>• ~125 - 140 dB re 1 <math>\mu</math>Pa</li> </ul>	Behavioural changes	Tank study, Canada
Tidau and Briffa, 2019	European hermit crabs ( <i>Pagurus bernhardus</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>• Tank playback 143.6 dB re 1 <math>\mu</math> Pa</li> <li>• &lt; 3000 Hz</li> </ul>	Behavioural changes	Tank study, England
Popper <i>et al.</i> , 2007	Rainbow trout ( <i>Oncorhynchus mykiss</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>• Playback of LFA sonar</li> <li>• 215 – 220 dB re 1 <math>\mu</math> Pa</li> <li>• SEL 188.5 -193 dB re 1 Pa<sup>2</sup>s</li> <li>• 170 - 320 Hz</li> </ul>	No effect	North America
Slater <i>et al.</i> , 2020	Whiteleg shrimp ( <i>Litopenaeus vannamei</i> )	5 - Shellfish	<ul style="list-style-type: none"> <li>• Tank playback</li> <li>• SPL 127 - 128 dB re 1 <math>\mu</math>Pa over an 8 week period</li> </ul>	No effect	Tank study, Germany
Slater <i>et al.</i> , 2020	Atlantic salmon ( <i>Salmo salar</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>• Tank playback</li> <li>• SPL 127 - 128 dB re 1 <math>\mu</math>Pa over an 8 week period</li> </ul>	No effect	Tank study, Germany
Nichols <i>et al.</i> , 2015	Giant kelpfish ( <i>Heterostichus rostratus</i> )	2 - Swim bladder where the organ does not appear to play a role in hearing	<ul style="list-style-type: none"> <li>• Tank playback</li> <li>• SPL 141.9 - 136.9 dB rms re 1 <math>\mu</math>Pa</li> <li>• 50 - 400 Hz</li> </ul>	No effect	Tank study, North America



The logo for MARA, consisting of the letters 'MARA' in a bold, blue, sans-serif font. The letters are slightly shadowed, giving them a 3D appearance as if they are floating above the water.

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