BLUEWISE MARINE

Revision number: 2
Document number: BD00722001

Impact of geophysical and geotechnical site investigation surveys on fish and shellfish

Desktop Study

REVISION HISTORY

Revision	Revision Text	Initials	Date
01	Initial draft for review	OD, RC, IC	22/08/2023
02	Final draft for release	OD, RC, IC, JB	06/10/2023

DOCUMENT CONTROL

	Name	Date
Prepared	Oisín Duffy, Rogério Chumbinho, Inés Coca	22/08/2023
Checked	Louise O'Boyle, John Breslin	23/08/2023
Reviewed	John Breslin	25/08/2023

DISCLAIMER

The contents of this report are intended for information and general guidance only and in no way legally bind the contributors to damage resulting from assuming it otherwise. The findings and recommendations within this report do not constitute advice, are not exhaustive and do not indicate any specific course of action. Detailed professional advice should be obtained before taking or refraining from action in relation to any of the contents of this report, or the relevance or applicability of the information herein. BlueWise Marine does not accept any liability if this report is used for an alternative purpose from which it is intended, nor to any third party in respect of this report.

Developed for Wind Energy Ireland (WEI)

THIS RESEARCH WAS MADE POSSIBLE BY THE GENEROUS SUPPORT OF A NUMBER OF WIND ENERGY IRELAND MEMBERS:

ACKNOWLEDGEMENTS

Contributions, data, and insightful comments received from various people and organisations have been fundamental to the successful completion of this study. BlueWise Marine is deeply grateful to John Lynch – Irish South & East Fish Producers Organisation (ISFPO), Teresa Morrissey – Irish Farmer's Association (IFA) Aquaculture Committee, Patrick Murphy - Irish South & West Fish Producers Organisation (ISWFPO), Séamus Breathnach – National Inshore Fishermen's Association (NIFA), Kevin Conneely - Western Inshore Fisheries Forum, Robert McCabe – Chair ORE Seafood WG, Justin Moran – Director Communications WEI, Dr. Colm Lordan – Marine Institute, Ian Lawler – Bord Iascaigh Mhara, Edward Farrell and Michael Keatin-ge, Killybegs Fishermen's Organisation.

BlueWise Marine is also thankful to the SFPA data services, the DAFM data services, Wind Energy Ireland and BIM, for providing detailed information on ORE developments, fisheries statistics and other spatial data.

CONTENTS

GLOSSARY VI

EXECUTIVE SUMMARY 1

1. INTRODUCTION 13

2. SITE INVESTIGATION SURVEYS 17

2.1. INTRODUCTION 17

2.2. GEOPHYSICAL SURVEYS 18
2.2.1. Purpose 18
2.2.2. Common techniques and equipment 18

2.3. GEOTECHNICAL SURVEYS 21
2.3.1. Purpose 21
2.3.2. Common techniques and equipment 21

2.4. METEOROLOGICAL AND OCEANOGRAPHIC SURVEYS. 22
2.4.1. Purpose 22
2.4.2. Common techniques and equipment 23

2.5. BIOLOGICAL SURVEYS.............................. 25
2.5.1. Purpose 25
2.5.2. Common techniques and equipment 25

2.6. REVIEW OF RECENT APPLICATIONS FOR SITE INVESTIGATION SURVEY LICENSE........................ 26

2.7. SUMMARY OF SURVEY TECHNIQUES AND CHARACTERISTICS.................................... 27

3. COMMERCIALLY IMPORTANT MARINE SPECIES IN IRELAND 30

3.1. GENERAL DESCRIPTION (MAP BASED) 30

3.2. LIST OF SPECIES FOR THE STUDY 39

4. REVIEW OF EFFECTS AND IMPACTS 42

4.1. INTRODUCTION 42
4.1.1. Physical impacts 45
4.1.2. Behavioural impacts.............................45
4.1.3. Physiological impacts 46
4.1.4. Other impacts....................................48

4.2. KNOWN EFFECTS OR IMPACTS ON FISH.............. 48
4.2.1. Physical impacts.................................48
4.2.2. Behavioural impacts 49
4.2.3. Physiological impacts........................... 50
4.2.4. Other impacts 52

4.3. KNOWN EFFECTS OR IMPACTS ON SHELLFISH, GASTROPODS, AND CEPHALOPODS 52
4.3.1. Physical impacts 52
4.3.2. Behavioural impacts 53
4.3.3. Physiological impacts 54
4.3.4. Other impacts 55

5. DISCUSSION OF IMPACTS 56

5.1. SPATIAL AND TEMPORAL EXTENSION OF KNOWN IMPACTS 56

5.2. UNKNOWN POSSIBLE IMPACTS 59

5.3. LIKELIHOOD, SPATIAL AND TEMPORAL EXTENSION OF IMPACTS 66

6. CONCLUSIONS 71

BIBLIOGRAPHY 75

APPENDIX 1 – BASICS OF OCEAN ACOUSTICS . . 82

APPENDIX 2 – DETAILS OF RECENT FORESHORE LICENSE APPLICATIONS FOR SITE INVESTIGATION SURVEYS 91

APPENDIX 3 – DETAILS OF LITERATURE REVIEWED TO BUILD IMPACT SUMMARY TABLES 104

Reduce waste

Double-sided printing is an effective way to reduce paper waste and save resources. Always evaluate the need for printing and consider alternative options such as digital storage or sharing before printing.

GLOSSARY

AA	Appropriate Assessment
ABM	Agent Based Models
AUV	Autonomous Underwater Vehicle
BIM	Bord Iascaigh Mhara
BWM	BlueWise Marine
CPT	Cone Penetration Testing
CSO	Central Statistics Office
DAFM	Department of Agriculture, Food and the Marine
DEB	Dynamic Energy Budget models
DECC	Department of the Environment, Climate and Communications
DHLGH	Department of Housing, Local Government and Heritage
DMAP	Designated Marine Area Plan
DP	Dynamic Positioning
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMFAF	European Maritime Fisheries and Aquaculture Fund
FLU	Foreshore Licensing Unit
HRG	High-Resolution Geophysical (see UHRS)
ICES	International Council for the Exploration of the Sea
JNCC	Joint Nature Conservation Committee
MAP	Maritime Area Planning
MARA	Maritime Area Regulatory Authority
MBES	Multibeam Echo Sounder
MI	Marine Institute
MMO	Marine Management Organisation (UK)
MPA	Marine Protected Area
MRE	Marine Renewable Energy
MSFD	Marine Strategy Framework Directive
NPWS	National Parks and Wildlife Service
ORE	Offshore Renewable Energy
OWF	Offshore Wind Farm(s)

PAM	Passive Acoustic Monitoring
PCAD	Population Consequence of Acoustic Disturbance
PCoD	Population Consequence of Disturbance
PTS	Permanent Threshold Shift
PVL	Particle Velocity Level (in dB ref 1 μm/s, except when explicitly stated otherwise)
RMS	Root Mean Squared
ROV	Remotely Operated Vehicle
SAC	Special Area of Conservation
SBP	Sub-bottom profiler
SEL	Sound Exposure Level (in dB ref 1 $\mu Pa^2.s$, except when explicitly stated otherwise)
SFPA	Sea Fisheries Protection Agency
SIL	Sound Intensity Level
SPA	Special Protection Area
SONAR	Sound Navigation and Ranging
SPL	Sound Pressure Level (in dB ref 1 μPa @1 m, except when explicitly stated otherwise)
SSS	Side-scan sonar
STECF	Scientific, Technical and Economic Committee for Fisheries
TL	Transmission Loss
TTS	Temporary Threshold Shift
UAV	Uncrewed Aerial Vehicle
UNRS	Ultra-high Resolution Seismic
USBL	Ultra-Short Baseline
USV	Uncrewed Surface Vehicle
VC	Vibrocore(s)
WEI	Wind Energy Ireland

EXECUTIVE SUMMARY

This document is a desktop study and report on the impact of geotechnical and geophysical surveys on commercially relevant fish and shellfish species. Work was grouped in the following main tasks spread over a total of about 15 weeks:

- Review of landings data from International Council for the Exploration of the Sea (ICES), Sea Food Protection Agency (SFPA) and the Central Statistics Office (CSO), as well as fishers-provided data, to determine commercially relevant species.
- Engagement with fishers to define the scope of work and agree on a list of relevant species the study should focus on.
- Identification of survey techniques and equipment more commonly used in site investigation surveys for offshore renewable energy developments, with the goal of determining their technical characteristics.
- Review of state-of-the-art literature on known impacts from underwater acoustic and mechanical pressures on marine species, arising from surveying activities.
- Cross-checking of learnings from the literature review with the species of interest in this study and the technical characteristics of common survey equipment, to identify and tentatively quantify possible effects of surveys.
- Discussion of the results of the review and learnings, and drawing of conclusions.
- Preparing and writing this Desktop Study report.

COMMERCIALLY SIGNIFICANT IRISH FISH AND SHELLFISH SPECIES

An analysis of landings data (both by weight and by value) from three main sources (ICES, SFPA and CSO) was carried out, with the goal of arriving at a list of the top 30 (approximately) most commercially significant fish and shellfish species in Irish fisheries; this list was reviewed by the representatives of the fishing sector, and a final list containing 37 species was agreed. These species were grouped into seven main groups, to facilitate the literature search and review of potential impacts on each species (or group) by site investigation surveys (see table below).

Study Group	Key Species
1. Generalist Fish (Low Sound Sensitivity)	Horse Mackerel Mackerel Megrim Monkfish Witch Flounder Plaice Sole Turbot
2. Specialist Fish (High Sound Sensitivity)	Boarfish Haddock Hake Herring Ling Saithe Sprat Whiting Blue Whiting Cod Albacore John Dory
3. Decapod Crustaceans	Brown Crab European Lobster Nephrops Crayfish (Palinurids) Green crab Velvet crab Spider crab
4. Gastropods	Whelk
5. Elasmobranchs (Sharks, Rays and Skates)	Small-Spotted Catshark Thornback Ray Blond Ray
6. Bivalves	Cockle Razor Clam Scallop Seed Mussel
7. Cephalopods	Common Squids European Flying Squid

Table 3.2 – Allocation of key commercially important fish and shellfish species to seven study groups.

COMMON SITE INVESTIGATION SURVEY EQUIPMENT

Meanwhile, a review of site investigation survey applications to the Foreshore Licensing Unit (FLU) was also carried out, with the purpose of collecting information on the equipment most commonly used in geophysical and geotechnical surveys, typical of preliminary site investigation for offshore developments. A total of 60 applications were reviewed corresponding to applications filed from 2020 onwards; of these, 4 are applications related to marine infrastructure, 2 to wave energy developments, and the remainder to offshore wind developments. Only 4 have received a determination, while 21 are currently in consultation. It is likely that many of these applications for license will not materialise into site investigation surveys, but this review enabled the collection of information on survey equipment mentioned in the applications. An additional document describing a state-led site investigation survey for the purpose of informing the establishment of a DMAP in the SE coast was also analysed in the same manner. The details of the FLU applications consulted can be found in Appendix 2. The final list of common survey equipment and their characteristic is shown in the Table 2.1.

All equipment uses or emits sound, as expected, and the subsequent scientific literature review focussed on scientific studies on the effects of sound on fish and shellfish; other possible sources of impact, such as mechanical vibrations, were also captured in the literature review.

LITERATURE REVIEW OF IMPACTS ON FISH AND SHELLFISH FROM ACOUSTIC AND MECHANICAL SOURCES

A systematic review of existing scientific literature on impacts on fish and shellfish from acoustic and mechanical sources was carried out. This review started with an analysis of five key review papers in this research topic (i.e., papers that present comprehensive reviews of a topic and summaries of the state of the art until then, based on other published research), namely Hirst and Rodhouse (2000), Caroll et al., (2016), Cox et al. (2018), Slabbekoorn et al. (2019) and Popper and Hawkins (2019). This analysis resulted in the identification of terminology, of key aspects of impacts and of their bounds, which formed the basis for a systematic search of four literatures databases: Web of Science, Google Scholar, Tethys, and Research Gate. The results of this search consisted of a list of scientific papers presenting details of the research of impacts of acoustic sources on fish and shellfish, published up to June 2023 (details in Appendix 3).These scientific papers were then analysed to single out the main result, or results, in each one, in what concerns the species being studied, the methods used, results achieved and conclusions. This body of work has been summarised in two “impact tables” 4.1 and 4.2, shown further.

Table 2.1 – Summary of acoustically active marine survey equipment, including mechanical sources (adapted from Ruppel et al, 2022; checked and complemented with information from vendors and manufacturers)

Marine Acoustic Source	Transmission Frequency	Source Level (dB re 1 µPa @ 1 m)	Example System(s)	Planned in surveys described in FLU applications
AIRGUNS, MARINE VIBRATORS				
Single airgun	15-60 Hz	216–235	Sercel 105/105 in³ GI-Source gun; Teledyne Bolt airguns up to 250 in³	Maybe
Airgun arrays	15-60 Hz	228–259	Multiple GI-Source or other airguns	No
Marine vibrator	5-100 Hz	unknown	Vibroseis experimental source	No
HIGH-RESOLUTION GEOPHYSICAL (HRG) SOURCES				
Boomer (seismic)	300-3000 Hz	185-207	Applied Acoustics S-boom	Yes
Sparker (seismic)	300-1400 Hz	185-226	Applied Acoustics Delta Sparker, SIG ELC sparker	Yes
Bubble gun (seismic)	20-2000 Hz	194-220	HMS-620	No
SUBBOTTOM PROFILERS (SBP)				
Hull-mounted	3.5, 12 kHz	199-232	Knudsen 3260 (4 x 4 array)	Yes
Shallow-towed	0.5-24 kHz	146-180	Edgetech 512i, Edgetech 424	Yes
Parametric	1-115 kHz	206-247	TOPAS, Innomar systems	Yes
HYDROGRAPHY				
Multibeam echo-sounder (MBES)	12-600 kHz	175-245	Kongsberg EM122, EM302, EM710, Reson 7160, ME70	Yes
Sidescan sonar (SSS)	65-500 kHz	196-224	L3 Klein 5000, Edgetech 4200	Yes
BIOLOGICAL ACOUSTICS – FISH FINDING SONARS				
Split beam echo-sounder (sonar)	18-333 kHz	212-229	Simrad EK60/80	No
Industry fish finder	14-220 kHz	< 200-210	Simrad SC90, ST90, SN90, SX90	No
OCEANOGRAPHIC ACOUSTIC INSTRUMENTS				
ADCP	38 to >300 kHz	211-227	Teledyne RD Workhorse	Yes
Scientific sonar (split beam)	Up to 1000 kHz	210-220	Bio-sonics DT-X Extreme	No
COMMUNICATION / TRACKING INSTRUMENTS				
Acoustic locators (pingers)	12-40 kHz	177-192	Edgetech CAT, Benthos UAT-376	Yes
Acoustics releases	8-34 kHz	184-192	Edgetech 8242, Sonardyne 7410	Yes
Underwater tracking systems	10-35 kHz	187-203	Applied Acoustics 1162, Edgetech 4380	Yes
GEOTECHNICAL EQUIPMENT				
Cone Penetration Testing	-	118-145	ROSON, Manta, G-Tech GT25, Fugro SeaCalf, Cambridge in-situ HDP95	Yes
Borehole	600 Hz -50 kHz	146-190	API drill string, Geobor „S“, Fugro C25	Yes
Vibrocores	50 Hz	180-190	Fugro HPC, OSIL VC	Yes

Table 4.1 – Summary of the observed impacts of low-frequency sound on fish. The numbers in the table refer to a specific scientific paper in which certain impacts were observed and are superscripted in those citations below.

	Generalist Fish (Low Sound Sensitivity)			Generalist Fish (Low Sound Sensitivity)							Elasmobranchs
Physical											
Air bladder damage	Ref. 3	Ref. 4		Ref. 3	Ref. 9	Ref. 17		Ref. 8			
Otolith/statocyst damage	Ref. 3	Ref. 4		Ref. 3	Ref. 9	Ref. 17		Ref. 8			
Organ/tissue damage	Ref. 3	Ref. 4	Ref. 16	Ref. 3	Ref. 9	Ref. 17		Ref. 8			
Mortality/abnormality	Ref. 3	Ref. 4	Ref. 16	Ref. 3				Ref. 8			
Behavioural											
Startle response	Ref. 6			Ref. 34							Ref. 28
Sound avoidance	Ref. 6			Ref.13	Ref.22	Ref.25	Ref.34	Ref.10	Ref.33	Ref.36	Ref.38
Foraging				Ref.5				Ref.13			
Reproduction				Ref.37							
Bioturbation											
Auditory Masking				Ref.2			Ref.18		Ref.28		
Attraction											Ref.27
Physiological											
Metabolic rates				Ref.34				Ref.35			
Stress bio-indicators				Ref.31		Ref.37		Ref.35			
Metamorphosis/settlement	Ref.16			Ref.7							
Catch Effects											
Catch rates/abundance	Ref.4	Ref.26	Ref.43	Ref.3			Ref.26		Ref.1	Ref.43	

Key:

- Response at Realistic Exposure Levels from sources not commonly used in Site Investigation Surveys
- Response at Unrealistic/Unknown Exposure Levels
- No Response
- Possible response/conflicting or anecdotal results
- No data
- Not applicable

Table 4.2 – Summary of the observed impacts of low frequency sound on marine invertebrates. The numbers in the table refer to a specific scientific paper in which certain impacts were observed and are superscripted in those citations below.

	Decapod Crustaceans			Gastropods	Bivalves		Cephalopods	
Physical								
Air bladder damage								
Otolith/statocyst damage	Ref.15	Ref.29	Ref.41				Ref.14	Ref.11
Organ/tissue damage	Ref.15	Ref.29	Ref.41					
Mortality/abnormality	Ref.15	Ref.29	Ref.41		Ref.39	Ref.44		
Behavioural								
Startle response	Ref.19		Ref.24		Ref.12			
Sound avoidance	Ref.20						Ref.22	
Foraging	Ref.42							
Reproduction								
Bioturbation	Ref.20		Ref.42					
Auditory Masking								
Attraction								
Physiological								
Metabolic rates					Ref.39	Ref.44		
Stress bio-indicators	Ref.23	Ref.40	Ref.29		Ref.30	Ref.39		
Metamorphosis/settlement					Ref.13			
Catch Effects								
Catch rates/abundance	Ref.3		Ref.33				Ref.3	

Key:

- (salmon) Response at Realistic Exposure Levels from sources not commonly used in Site Investigation Surveys
- (yellow) Response at Unrealistic/Unknown Exposure Levels
- (green) No Response
- (blue) Possible response/conflicting or anecdotal results
- (grey) No data
- (light grey) Not applicable

As seen in the tables above, impacts were classified as Physical, Behavioural, Physiological and Other (mainly impact on catch rates), and the results from available research used to characterise any of these impacts, as observed and reported. It can be seen that significant knowledge gaps exist in research for several species (e.g., no results or research on whelk was found in the literature), and that results sometimes are inconsistent, or obtained under unrealistic laboratory conditions. It should also be noted that most research focuses on the impacts resulting from powerful sound sources, such as airguns and airgun arrays, which are not expected to be used in ORE site investigation surveys.

DISCUSSION OF RESULTS FROM SCIENTIFIC RESEARCH CROSS-CHECKED WITH THE LIST OF KEY SPECIES

A discussion of the limitations of current research and how they must be considered when assessing the impacts described in the above tables, in the scope of this study, can be found in section 5. The discussion is divided into two parts: the first part attempts to look at possible impacts of site investigation surveys on the key species of interest in this study, and the second discusses possible unknown impacts and the likelihood, temporal and spatial extension of impacts.

Possible impacts of sound sources that could arise from site investigation surveys are summarised in the Table 5.1.

The colour codes used in the rightmost column of the table are used to highlight whether the possible impacts from surveys are either: i) **unlikely**, due to the specific instrument(s) not being used in site investigation surveys (in grey); ii) **possible**, due to the instruments being planned for use in site investigation surveys (dark yellow) or; iii) **likely**, due to causes not just specifically accountable to site investigation surveys (light yellow), as for instance, vessel noise from any vessel other than, but possibly including, the survey vessel.

Table 5.1 – Study groups and key species of interest, observed impacts resulting from noise sources in research and possible impacts from surveys.

Study group	Species	Observed impacts documented in research	Experimental sound source	Possible source(s) in surveys
Generalist Fish (Low Sound Sensitivity)	Horse Mackerel Mackerel Megrim Monkfish Witch Flounder Plaice Sole Turbot	No significant impact found to date in research. Temporary change in behaviour	Low frequency Airgun noise	Airgun / airgun array
Specialist Fish (High Sound Sensitivity)	Boarfish Haddock Hake Herring Ling Saithe Sprat Blue Whiting Whiting Cod Albacore John Dory	Physical: Air Bladder Damage, Otolith Damage, Organ/Tissue Damage	Low Frequency Airgun Noise	Airgun / airgun array
		Behavioural: Sound Avoidance, Foraging, Reproduction, Auditory Masking	Low Frequency Airgun Noise	Airgun / airgun array
			Lab-Based Playback of 120 dB Noise, repeated impulsive noise, Ship noise	Geotechnical and geophysical surveys, survey vessel noise
		Physiological: Metabolic Rates, Stress Bio-Indicators, Metamorphosis/Settlement	Lab-Based Playback of 120 dB Noise, pile-driving noise, linear sweeps	Geotechnical and geophysical surveys, survey vessel noise
		Catch Effects: Catch Rates/Abundance	Low Frequency Airgun Noise	Airgun / airgun array
		Physiological: Metabolic Rates, Stress Bio-Indicators, Metamorphosis/Settlement	Lab-Based Playback of 120 dB Noise, pile-driving noise, linear sweeps	Geotechnical and geophysical surveys, survey vessel noise
		Catch Effects: Catch Rates/Abundance	Low Frequency Airgun Noise	Airgun / airgun array
Decapod Crustaceans	Brown Crab European Lobster Nephrops Crayfish (Pali-nurids) Green crab Velvet crab Spider Crab	Behavioural: Startle Response, Sound Avoidance, Bioturbation	Lab-Based Playback of pure noise, pile-driving noise	Geotechnical surveys, survey vessel noise
		Physiological: Stress Bio-Indicators	Lab-Based Playback of vessel noise	Vessel noise

Study group	Species	Observed impacts documented in research	Experimental sound source	Possible source(s) in surveys
Gastropods	Whelk	No studies currently available on this group	-	-
Elasmobranchs (Sharks, Rays and Skates	Small-Spotted Catshark Thornback Ray Blond Ray	Behavioural: Startle Response, Sound Avoidance, Attraction	White Noise Generators	Geotechnical surveys, vessel noise
Bivalves	Cockle Razor Clam Scallop Seed Mussel	Behavioural: Startle Response	Lab-Based Playback of low frequency Airgun noise	Airgun / airgun array
		Physiological: Metabolic Rates, Stress Bio-Indicators, Metamorphosis/Settlement	Lab-Based Playback of pile-driving and drilling noise plus shaker to cause particle motion (a ≤ 0.55 ms-2)	Geotechnical surveys, borehole
Cephalopods	Common Squids European Flying Squid	Physical: Statocyst Damage	Lab-Based Playback of sinusoidal wave sweeps 50 – 400 Hz	Geotechnical surveys, Vibrocore, airgun / airgun arrays (distance dependent)
		Behavioural: Sound Avoidance	Low frequency airgun noise	Airgun / airgun array

The second part of the discussion (unknown impacts) reviewed all the constraints, limitations, and difficulties with extrapolating the results found in this study to unknown impacts (i.e., impacts that have not been documented in literature). This included eventual biases in the results from research, limitations in the classification of fish between generalist and specialist, the constraints of laboratory experiments, the measurement and use of Sound Pressure Levels (SPL) as the most prominent sound characteristic in most research experiments, possible and unclear effects of particle motion on fish and shellfish, the effect of other characteristics of sound (e.g., sound pulses, their rising and fall times, and their repetition rate), and the combined effect of SPL and duration of the sound source, known as Sound Exposure Level (SEL). The short and long term responses of fish and shellfish populations were also discussed, highlighting recent research towards a better understanding of the latter, as well as the spatial and temporal extents of impacts expected in site investigation surveys, and the difficulties in drawing conclusions in this regard.

The main points of the discussion are summarised below:

- The principal cause of concern (for fish and shellfish) from site investigation surveys is the use of sound by marine survey instruments.

- Of these, the most impactful instruments are those used in high resolution geophysical (HRG, also known as seismic) surveys, such as single airguns and airgun arrays.

- Nearly all site investigation surveys do not plan to use airguns or airgun arrays and, thus, should be more benign to fish and shellfish than seismic surveys (which have been the major driving force for the vast majority of impacts found in the scientific literature).

- Boomer and sparker systems, also used in HRG surveys, operate at lower power levels, as do most other research instruments, and should be less impactful than airguns.

- It is generally accepted that most research instruments used in site investigation surveys do not cause significant impacts to fish and shellfish.

- Instant mortality of both fish and shellfish due to site investigation surveys is very unlikely. During this desktop study, no documented evidence of significant fish or invertebrate mortality due to these surveys was found.

- Impacts on fish and shellfish behaviour during the survey is likely and mostly temporary. This impact is most commonly behavioural, although some species may suffer physical impact (depending on several factors such as SPL, cumulative SEL, distance to the source, sensitivity to acoustic noise, sensitivity to particle motion, capacity to find shelter, capacity to leave the area). Whether the temporary behavioural or reduced physical impact have population level consequences is currently not known, although the coexistence of fisheries with other forms of marine exploitation in many areas suggest that any population level consequence on fisheries could be minimal.

- The impact from site investigation surveys will be most noticeable in the close vicinity of the survey, up to a few thousand meters of the survey vessel, and particularly around the vessel's vertical. As the survey vessel covers the survey site and since the survey area is usually much larger than this, the impact will be distributed throughout the area; however, depending on the survey plan and the area extent, the effects on fish and shellfish will vary in time across the survey area.

- It cannot be generalised that the impact eventually observed on an individual in a sub-area of the survey site will be found in individuals of the same species in other sub-areas, or in individuals of similar species.

- Positive and negative effects on fisheries (catches) during surveys have been reported; however, in practical terms, fishing activity is restricted in surveys areas altogether, and this could be more impactful on catches than the impacts of the survey itself.

- Research has found that it is difficult to accurately determine impact of the survey in the post-survey phase, since there are other environmental and physiological factors that may be significant as well. Several studies have found that catches tend to recover in time (from days to several weeks), but this is inconclusive.

RECOMMENDATIONS

Site investigation surveys may cause some sort of impact (as defined in this study), depending on several factors. Although critical impact to fish and shellfish populations from site investigation geophysical and geotechnical surveys is highly unlikely, the exact nature and extent of minor impacts (such as avoidance or habituation) is currently not well understood. It could be argued that the relative absence of long term impact studies in research, and the continued fishing operations in areas subject to high marine engineering and construction activities for decades, such as the

North and Baltic Seas, are indicative that long term effects on fisheries are not significant enough to profoundly impact fisheries. Therefore, even lesser impacts could be expected from the much less impactful, temporary activities typical of site investigation surveys (in fact, MBES and SBP have been used worldwide for the last half-century or so, with no reports of significant, if at all, harm to marine life).

In the research review carried out in this study no evidence was found of direct impacts attributable to site investigation surveys. However, as a matter of caution, it seems good practice to use mitigation measures similar to those in place for marine mammals (e.g., soft-start, avoid spawning and breeding seasons), try and minimise the number of geotechnical and geophysical surveys in the same or adjacent areas, or to space them in time, to allow fish and shellfish populations to recover in between, and to share existing data to the largest extent possible.

There are many aspects of sensory information processing by fish and shellfish that are still unknown, affecting our understanding of the extent and nature of impacts that human activities cause on fish and shellfish. Further laboratory-based research to address these gaps will consequently help better understand the potential population level impact of geophysical and geotechnical site investigation surveys. To gain a comprehensive understanding of these impacts, research that focuses on the specific types of equipment used in these surveys is needed to gain insight into how they might affect the behaviour or physiology of relevant commercially fished species. There are commercially fished species, such as the common whelk, for which there have been no relevant studies. This research will likely be driven by scientific curiosity rather than by industry needs.

Instead, the offshore renewables industry could perhaps address shorter term goals. Further studies, such as using scientific echosounders mounted on AUVs to record echograms on fish shoals and schools during surveys, and visual monitoring of less mobile species or collection of biological samples, could provide useful information to assess fish (and possibly shellfish) behaviour during geophysical and geotechnical surveys. These studies could be supported by pre-survey and post-survey monitoring. As Ireland moves into a plan led approach to ORE developments, with centralised site investigation surveys favoured over developer led surveys, this could be the ideal timing to add these much needed components to the proposed survey work.

1. INTRODUCTION

BlueWise Marine (BWM) has been engaged by Wind Energy Ireland (WEI) to deliver a desktop study on the impact of Site Investigation Surveys on Fish and Shellfish.

As part of the preparation process for offshore renewable energy (ORE) developments (in fact, for any engineering activity in the marine environment), the collection of environmental data is essential to inform downstream activities such as design of structures and infrastructures, planning of operations, consenting, assessment of environmental impact, etc. This process starts with a review of existing environmental data for the target site, usually followed by a dedicated survey to collect specific or more detailed data. These preliminary surveys are known as Site Investigation Surveys (other surveys may be required later in the development to acquire even more detailed information).

Ireland's Offshore Wind Energy programme includes a target to deploy at least 5GW of offshore wind energy by 2030, as part of the Government's objective to generate 80% of Ireland's electricity from renewable sources by 2030. These decarbonisation goals have resulted in a significant interest from wind farm developers to develop projects in Irish waters. Initially led by the developers themselves, this interest has resulted in a high number of applications for Site Investigation Surveys throughout Ireland's Territorial Sea and EEZ filed with the Foreshore Licensing Unit (FLU) (see Figure 1.1). This, in turn, led to an increasing concern among the fishing communities regarding whether and how these surveys (sometimes overlapping in the same area or at the same time) might reduce catches of fish and shellfish in addition to displacing fishers from their grounds. Concerns arose over possible physical, behavioural and physiological impacts.

The transition to a plan-led approach to ORE developments has made it clear that many of the Phase 2 developer led surveys will not take place. Nonetheless, the need to better understand the possible impacts of Site Investigation Surveys on the locally important fish and shellfish species remains. This desktop study aims to identify the nature and extent of the impacts which have been observed following scientific surveys and experiments to assess the impacts of geophysical and geotechnical equipment and surveys on fish and shellfish.

Given the diversity of marine life (even when only the commercially important fish and shellfish are considered) and of environmental factors affecting it, the assessment of the likely impact of Site Investigation Surveys is no simple task. As it will be seen in later sections of this study, surveys largely use sound and me-

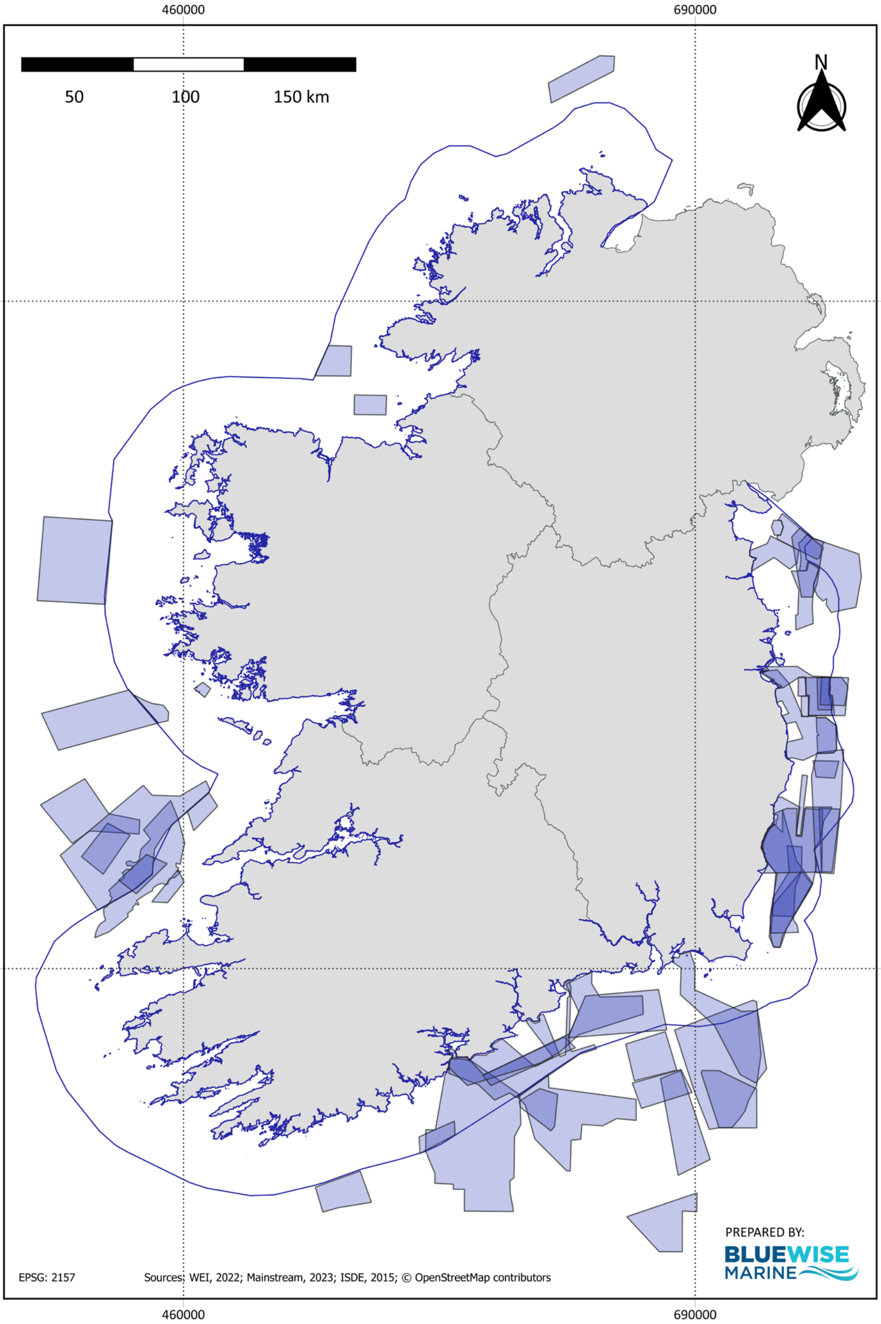


Figure 1.1 – Site Investigation applications for Irish Offshore Projects.

chanical devices to collect data, sediment samples and cores. The scientific community has been studying ocean acoustics for more than a century, and the impact of sound on marine life for several decades already. However, early studies were focused on impacts on large marine mammals, and then later on all marine mammals (in fact, the effects of sound on marine mammals became a major and mediatic source of concern and the object of conservation measures 40 or 50 years ago).

Only more recently (from the late 1970s) have studies about similar effects on fish and shellfish become available. The research on this topic was driven originally by public awareness of the levels of sound produced during high resolution seismic surveys carried out by the Oil and Gas industry and possible impacts on marine mammals (first) and on fish (later), and also by the need to understand the response of commercial fish species to sound produced by equipment such as fish finding sonars and trawl net locators. Unsurprisingly, a large number of studies and reviews focus on high intensity, low frequency sound sources, such as those produced by the airgun arrays used during high resolution seismic studies.

Studies on the impacts of underwater acoustics have gradually expanded to understand the effect of anthropogenic acoustic noise in general, spanning all frequency ranges and sound source levels. In recent years, these studies have increased significantly (apparently motivated by scientific curiosity) and a relatively large number of studies on diverse aspects of impact of sound on marine species is now available online. Despite this fact, there are significant knowledge gaps. For instance, while there are several studies on important commercial finfish species such as cod, herring, or mackerel (or similar), studies on shellfish are less common and in the case of gastropod molluscs such as whelk are non-existent. Furthermore, research tends to focus on controlled experiments using, for example, fish and shellfish within confined tanks. These results need to be carefully assessed as they often misrepresent the physical scale, fish behaviours and conditions found in the open sea environment.

To address the above challenges and in an attempt to arrive at meaningful and useful results, BWM developed a workplan that included the following steps:

- Review of data made available by the International Council for the Exploration of the Seas (ICES), the Sea Fisheries Protection Agency (SFPA), the Central Statistics Office (CSO) and by fishers or fisheries associations to determine commercially relevant species.

- Engagement with fishers to define the scope of work and agree on a list of the most commercially important species the study should focus on.

- Identification and description of survey techniques and equipment more commonly used in site investigation surveys for offshore renewable energy developments, to quantify the relevant acoustic properties such as source levels and frequencies, since underwater sound is the most important man-made disturbance to the marine environment during surveys.

- Systematic review of scientific literature on known impacts from underwater acoustic and mechanical pressures on the marine species of interest for the study, arising from surveying activities, as well as consultation with relevant organisations

(Bord Iascaigh Mhara, Marine Institute). In the case literature was not found for a specific species, the review used literature on similar species (physiologically, or those belonging to the same taxonomic family or genus).

- Cross-checking of learnings from the literature review with the species of interest in this study, to identify and tentatively quantify possible effects of surveys on those species.

- Discussion of the results of the review and learnings and drawing of conclusions.

- Preparing and writing this Desktop Study report.

This report, detailing the results of the above workplan, is structured as follows:

- Section 2 contains a description of the typical research activities carried out during Site Investigation Surveys (sub-sections 2.2 to 2.5), an analysis of current Site Investigation License applications in terms of surveys foreseen and type of equipment expected to be used (sub-section 2.6), and a compilation of the technical characteristics of the acoustic devices (or sound producing equipment) used in Site Investigation Surveys and in other marine activities such as fishing (e.g., fish finding sonars), in sub-section 2.7;

- Section 3 presents the results of the fisheries data analysis, listing the most commercially important fish species in each region of Irish waters with the help of illustrative maps. Based on these listings, which have been validated with the assistance of representatives of fishers and their associations, a list of the most commercially significant species has been produced, further grouped into seven groups of species.

- Section 4 contains details of the systematic scientific and technical literature review of known impacts of sound on fish and shellfish, focusing on the species or groups identified and validated in section 3.

- Section 5 discusses the possible extension of known impacts into the context of Site Investigation Surveys, based on the findings from previous sections, as well as a discussion of unknown impacts and their likelihood; and

- Section 6 contains concluding remarks.

2. SITE INVESTIGATION SURVEYS

This section describes the purpose of site investigation surveys carried out in the context of ORE development, the types of surveys and the instruments or equipment more commonly used in the surveys.

2.1 INTRODUCTION

Acquisition of knowledge about the different physical, chemical, and biological characteristics of the ocean and its borders (the air-sea interface, the seafloor and the shore) is achieved by means of observations made with marine surveys or deployed sensors. In present days, marine surveys are highly specialised operations designed specifically for the goals of the survey, which can include acquisition of data on the morphology and composition of the ocean bottom, or on the dynamics of the ocean environment, or on the chemical and biological properties of seawater, or – more frequently – a mix of all the preceding goals. Depending on the goal or goals, marine surveys can be given descriptors (e.g., a hydrographic or bathymetric survey measures the morphology of the ocean bottom, a geophysical survey acquires information of the nature of the seafloor and its substrates, a geotechnical survey is focused on mechanical properties of the seafloor and substrates, a biological survey measures properties relevant for marine life in its various forms, etc.).

Marine surveys typically utilise sophisticated equipment or sensors. In many cases, information is obtained indirectly, that is, the information of interest is not obtained by direct measurement of the property, but it is primarily obtained by its effect on the propagation of sound (e.g., water depth is commonly obtained by measuring the travel time of sound waves of known velocity). The technological advancement resulting from a growing knowledge of the subtle effects of seawater properties (or those of its boundaries, such as sand or rock) on sound propagation – that is, on reflection, refraction, and absorption of sound energy – and the expanding capacity of modern signal processing have both led to a multitude of equipment that use sound as their main method of detection and data acquisition. This has also led to the availability of instruments that measure several parameters simultaneously (e.g., a modern geophysical survey commonly includes both bathymetry and seismic – either on or below seafloor substrate – information).

Site Investigation surveys are a subset of marine surveys that are tailored to provide necessary information for the site being investigated which, in this study, relates to ORE developments. These projects encompass complex engineering requirements for structures typically designed to withstand 25 years within the marine environment. Consequently, the fulfilment of these requirements must be based on a thorough knowledge of the marine environment in the chosen area.

Although site investigation surveys can vary slightly depending on the specific ORE technologies planned for deployment or utilisation in the site, they are generally comprised of:

- **Geophysical surveys** (details in section 2.2)
- **Geotechnical surveys** (details in section 2.3)
- **Meteorological and oceanographic surveys** (details in section 2.4)
- In most cases, also elements of **biological surveys** (details in section 2.5)
- **Archaeological surveys** (these surveys analyse data from geophysical or geotechnical surveys in search of archaeological evidence. Since they generally do not use specific equipment beyond that already analysed in other types of surveys, archaeological surveys will not be further explored in this study).

The following sections provide details on each of the above types of surveys.

2.2 GEOPHYSICAL SURVEYS

2.2.1 Purpose

A Geophysical Survey focuses on measuring properties such as water depth, composition of the seafloor (e.g., indirect detection of the type of substrate on the seafloor), detection and morphology of sediment layers, detection of the rocky substrate layer under the ocean bottom sediments, measurement of the sediment thickness, detection of significant obstacles (e.g., rocky outcrops on a sandy bottom), and the detection of any human artifacts that may endanger the future development, such as wrecks or unexploded ordnance.

2.2.2 Common techniques and equipment

Marine surveys are unable to make use of visible light except at very shallow depths, as is the case with terrestrial scientific surveys; therefore, marine geophysical surveys must utilise the propagation of acoustic energy within the water column, and on and below the seabed. The simplest and earliest form of using sound in the ocean is the SONAR (Sound Navigation and Ranging), which could gather information on the bearing and distance of a target (sound reflector). Currently all three physical processes involved in sound propagation (reflection (including backscatter), refraction and absorption) are used to derive useful information.

Sound propagation in the ocean depends on multiple factors, including frequency of the sound waves, intensity, and duration of the sound at the source, beam-forming capacity of the source or receiver, distribution of temperature and salinity in the water column, abundance of suspended particulate matter, and acoustic characteristics of the sea floor and other reflectors. In addition to these factors, which influence propagation, the signal received by the transceiver is further dependent of the acoustic range, bandwidth and sensitivity of receivers, multi-path propagation, ambient noise (signal to noise ratio), and relative velocity of the receiver versus the medium, among other factors. See Appendix 1 – Basics of ocean acoustics for further details.

In spite of the underwater acoustic channel being one of the most challenging mediums for the utilisation and interpretation of acoustic energy, advancements in underwater acoustics have resulted in a plethora of equipment successfully exploiting many of the above-mentioned factors, cleverly using combinations of frequencies, sound power and signal processing to maximise the extraction of useful information from the acoustic signals received (and emitted) by the equipment. The most commonly used equipment and their main characteristics are listed below.

- **Multi-beam echo sounder (MBES):** This instrument uses sound to derive water depth and the nature of the materials composing the sea bottom. It sends sound in pulses at different frequencies (higher frequencies for shorter range and higher resolution, lower frequencies for improved range at the expense of lower resolution); the receiver forms beams at various angles relative to the vertical and it is thus capable of achieving a wider bottom coverage than the single beam echo sounders of the early days, providing depth data on “swaths” about the vertical rather than just data points on the vertical. It is often used coupled with a sub-bottom profiler (in some models, the same acoustic energy is especially processed to derive both types of data). Examples of typical instruments are included in the summary table in section 2.7.

- **Sub-bottom profiler (SBP):** Under certain conditions, the acoustic energy released into the water column can penetrate the sea floor, being then refracted and reflected as the density of the materials composing the sediment layer and/or rocks underneath varies. The acoustic signals received after these processes take place provide a more or less clear image of the composition and morphology of the sediment layers and rocky substrates beneath them. SBPs are usually classified according to their penetration ability and resolution. Low power, higher frequency SBPs usually penetrate less in the sediments but are able to quantify their thickness, probable composition (which causes variation in the intensity of the signal received) and general layered arrangement (this technique is also called light- or shallow seismic, due to its resemblance with seismic studies on land). Examples of typical instruments are included in the summary table in section 2.7.

- **High-Resolution Geophysical Seismic (HRGS):** These systems are employed after a first survey done with lower power SBP, to further investigate regions of interest; in the Oil and Gas industry, HRGS systems are used to make detailed maps of the sediments and rocky substrates. They can assume several configurations (e.g., air guns and arrays, boomers, sparkers) differing in the way sound is produced (injection of high-pressure air in the ocean, electrically actuated diaphragm or electrical spark, respectively). These systems are generally capable of producing very high power sound sources, with lower frequencies than SBPs, and thus allow for much deeper penetration into the sediments and rocky substrates composing the ocean floor, from tens to hundreds or thousands of meters, giving more detail on structures that lay deep in the seabed. Examples of typical instruments are included in the summary table in section 2.7.

- **Side-scan sonar (SSS):** These instruments take advantage of the shadow effect of reflected sound waves, much the same way as light in the atmosphere is shadowed by obstacles. Analysis of the shadows can provide details of the obstacles. The instrument is usually towed behind the survey vessel, at some small enough distance above the ocean floor. It emits sound at relatively high frequency and power sideways (as well as vertically, to control depth); the reflections thus received are very useful to detect small features of the sea floor that would be harder to detect otherwise, as they show up in a continuous sound record as "shadows". They also assist in the identification of those features (e.g., wrecks, rocky outcrops and other small features, natural or man-made). Examples of typical instruments are included in the summary table in section 2.7.

- **Magnetometer / gravimeter:** These instruments measure anomalies in the magnetic or gravity field of the surveyed area, respectively. Anomalies in the magnetic field can be due to changes in the chemical composition of the rocks on or below the sea floor, as well as due to ferromagnetic materials deposited on the floor (e.g., pipelines, cables, wrecks, unexploded ordnance or other structures). Anomalies in the gravity field are mainly caused to variations in the mass of materials that compose the seafloor, with denser materials causing higher anomalies. Thus, both instruments can provide insights into the composition of the sea floor (the magnetometer can also be used to help identify structures on the seabed). Neither uses sound, and both are completely passive. Examples of typical instruments are included in the summary table in section 2.7.

2.3 GEOTECHNICAL SURVEYS

2.3.1 Purpose

The goal of a Geotechnical Survey is to study the morphology, composition and mechanical properties of the sediments of the sea floor and, often times, of the rock below. This is done not indirectly, as in geophysical surveys, but by direct sampling and testing carried out on the sediments and rocks (although the testing may use sound (e.g., sound pulses to measure mechanical properties of the sediment or rock), the sound is released into the sediment or rocky medium, not in the water column). The data obtained in these surveys is vital to inform critical parameters in the design of adequate marine structures (foundations, pillars, moorings, etc.). Therefore, a geotechnical component is nearly always present in site investigation surveys, regardless of the type of ORE envisaged.

2.3.2 Common techniques and equipment

- **Cone Penetrative Testing (CPT):** Cone penetrative tests are used to test the characteristics of the soil at the seabed by pushing an instrumented rod-shaped tool with a conical head of known apex angle into the ocean floor at a constant speed, with continuous measurement of the cone end resistance, the friction along the sleeve of the cone, and the pore water pressure. The resulting combination of these three parameters provides a signature for the soil, allowing the type of material and stratification to be identified, as well as providing direct strength parameters for engineering design, such as information that can be correlated to the undrained shear strength in clays, and relative density and angles of shearing resistance in sandy sediments. CPTs can be carried out using equipment that is deployed at the seabed, or from a surface platform. Examples of typical instruments are included in the summary table in section 2.7.

- **Vibrocores (VC):** This type of equipment is used to obtain a (usually) cylindrical core sample of the sediments. The instrument uses vibration or rotation to dig a hollow sampling cylinder into the sediment layer, which is then carefully removed once refusal (no further progression) or a predetermined depth is attained. The resulting sample can span several meters of sediment layer, with detailed "in situ" information of the geological composition of the seabed and its substrates. This allows for extrapolation or determination of mechanical properties in the lab, or to validate and cross-check other data obtained indirectly (e.g., via SBP). Examples of typical instruments are included in the summary table in section 2.7.

- **Borehole:** A borehole is a method of drilling into the ocean floor, for direct sampling of sediments or rocks, or to carry out geotechnical tests at various depths in the sediment or rock layers (down-hole testing). A drilling head is lowered to the sea floor and stabilised prior to commencement of drilling. Tools are then lowered into the drill to recover samples or conduct in-situ soil geotechnical testing to evaluate soil properties. Boreholes are typically performed from a platform at the surface (e.g., a dynamic positioning (DP) vessel or a jack-up barge). Examples of typical instruments are included in the summary table in section 2.7.

- **Grab sampling:** These instrument are designed to directly sample a small amount of superficial seabed sediment and bring it to the surface for analysis. It can be used to ground-truth indirect data, or as a means to collect data for environmental surveys (including biological aspects such as micro fauna and flora in sediments). Examples of typical instruments are included in the summary table in section 2.7.

2.4 METEOROLOGICAL AND OCEANOGRAPHIC SURVEYS

2.4.1 Purpose

Meteorological and Oceanographic surveys are designed to improve understanding of the dynamics of atmosphere and ocean at the survey site, respectively. Although systematic observations taken by official entities such as meteorological offices or marine institutes are available, as well as a multitude of meteorological and oceanographic models that can provide insights on average conditions, ocean and atmosphere dynamics can vary significantly in time and space, for which reason modelled output may be considered not representative enough for engineering purposes, and thus a need for local surveys. High temporal and spatial variability also accounts for the fact that observations can span a considerable time interval (a few years, in some cases) so that the acquired data can be considered statistically significant and processed accordingly.

Properties typically measured include wave, current and wind statistics (e.g., maximum and mean wind speed and direction, mean significant and maximum wave height, direction and period, etc.). Whenever possible, these measurements are also done vertically, along the water column and above the ocean surface (vertical wind and current profiles) and not only at the surface (or at the reference level of 10m above the surface in the case of wind). The above environmental properties, among others, are essential to inform many design parameters influenced by wind, wave and current, such as forces on moorings, on fixed and floating structures and on wind turbines, as well as for estimation of power output from the ORE devices themselves. Further, it is often necessary to measure the same set of parameters continuously after commencement of operations of ORE devices, for device control and preventive maintenance purposes.

In some cases, especially in areas of significant temporal and spatial changes in non-consolidated sediments, it may also be required to acquire data on sediment dynamics.

2.4.2 Common techniques and equipment

- **Current measurement:** Modern day ocean current measurements are typically done availing of sound, using instruments based on acoustic Doppler profiling. Instruments using this technique transmit 4 or 5 simultaneous beams of acoustic energy, at known angles to the vertical, and listen for reflections from suspended matter in the moving water column. These reflections are split into time-based bins, each thus corresponding to a specific depth range, and the doppler shift of the reflections measured with great accuracy. This allows for the determination of water velocity components which, when combined using information from at least four beams, provides a vertical profile of three-dimensional velocity vectors. Spatial orientation to align these vectors to true or magnetic North is done by means of an internal compass or gyroscopes. Parameters such as power, frequency and pulse duration determine the maximum range, accuracy, and resolution of the instruments. These instruments are usually also capable of determining the movement of the air-sea interface (surface gravity waves), especially those equipped with the 5th beam (and "looking" upward). Examples of typical instruments are included in the summary table in section 2.7.

- **Wave measurement:** The measurement of waves at the ocean surface (surface gravity waves) is currently done with purpose-built buoys. These buoys contain accelerometers, arranged in a configuration that allows determination of accelerations in three orthogonal directions and, from these, the displacement of the buoy due to the action of waves. A compass allows for alignment with true directions. Some instruments complement these measurements with precision GPS data. Examples of typical instruments are included in the summary table in section 2.7.

- **Wind measurement:** Measurements of wind are typically done with anemometers; however, these cannot practically and efficiently acquire wind data with sufficient range and resolution for offshore wind farms (OWF), which need high-resolution vertical profiles of wind speed and direction. Modern surveys thus use instruments based on LiDAR (Ligh Detection and Range), either deployed on buoys or on land. These use the same principle described for acoustic doppler ocean current measurements but using light instead of sound. LiDAR-based instruments can be used with the light beams oriented vertically, providing the vertical profiles of wind velocity required by OWF. These are then processed for extraction of statistics and design parameters for turbines and other structures. Examples of typical instruments are included in the summary table in section 2.7.

- **Sediment traps:** These instruments measure the rate of sediment re-suspension of deposition, as well as sediment fluxes. This is done by optically measuring the rate of change of concentration of sediments in a controlled environment, with known input and output. The optical sensors are positioned in boxes lowered in a frame to the ocean floor; the frame is also equipped with a current meter and a data logger.

- **Underwater positioning:** A marine survey usually requires the use of a significant number of equipment deployed underwater. Some types of underwater equipment, such as SSS sensors, hydrophone lines, Remotely Operated Vehicles (ROV) or autonomous vehicles carrying sensors, must be accurately positioned, either in absolute terms or in relation to a deployment platform (e.g., a vessel). This is achieved in modern surveys using Ultra-Short Baseline (USBL) technologies (some SSBL – Super-Short Baseline). Instruments capable of providing USBL positioning services use acoustic waves, in short pulses, to interrogate and determine the bearing and range of specially designed responders; these responders are installed in the equipment whose position must be determined. Once interrogated, they respond with their own pulse. The name Ultra-Short Baseline derives from the fact that the interrogator uses three or more sensing heads (transducers) spread over a distance of only 10 cm or less to determine the bearing of the responders. Examples of typical instruments are included in the summary table in section 2.7.

2.5 BIOLOGICAL SURVEYS

2.5.1 Purpose

Biological surveys are carried out to assess the nature and extent of marine life in the site investigation area. This assessment is, of course, virtually impossible to achieve, given the scales and diversity of marine life. Therefore, when included in Site Investigation surveys, biological surveys are usually designed to better inform specifically on eventual impacts on local macroscopic marine life (fauna and/or flora), or to assess potential impacts on nearby specially delimited areas for nature conservation (e.g., marine protected areas (MPA), NATURA 2000 areas, special areas of conservation (SAC), special protection areas (SPA)), or to assess eventual impacts on known fishing grounds (habitats, spawning grounds, etc.). In most cases, the surveys pay particular attention to marine mammals since many of these species are protected and most equipment operates at frequencies within their hearing range, and also to marine birds and their habitats; more rarely, some surveys also require assessments of fish and shellfish species present in the site area.

Different techniques are used in this type of surveys, very often using visual inspection or surveillance of marine mammals or birds, nets and traps for fish and shellfish capture, inspection of sediment grabs (section 2.3.2), etc. Underwater visual inspections use drop-down or towed video cameras or, in some cases, remotely operated vehicles (ROV).

2.5.2 Common techniques and equipment

- **Passive Acoustic Monitoring (PAM):** This monitoring usually targets marine mammals and is completely passive, that is, there is no emission of sound by the PAM instrument. These are typically composed of one or more hydrophones, a simple data processor and a data recorder. They can record from a broad range of frequencies emitted by marine life to specific sounds at pre-determined frequency bins (e.g., echo-location pings). These recordings can be used to detect the presence of marine mammals, their species and, in some cases, the number of individuals and their estimated distance to the recording instrument. The recordings can also give an indication of the level of ambient noise in the area (i.e., the background acoustic noise level resulting from natural and anthropogenic sources, either in the far or near fields of the site area). Examples of typical instruments are included in the summary table in section 2.7.

- **Fisheries assessment:** Fisheries assessments are designed to assess the current status of a stock, compare that to past statuses, and forecast future statuses under different conditions. Stock assessment methods vary depending on the stock being assessed and the data the assessments are trying to obtain. Assessment of variability in stocks using acoustic tagging and tracking, fish finding sonars, catch or landings per unit effort (CPUE/LPUE), camera surveys, such as camera tows or baited remote underwater video (BRUV) and direct sampling. BACI (Before-After Control-Impact) and BAG (Before-After Gradient) methods (Methratta, 2020) are used in impact assessments, e.g., before and after a survey campaign, or before and after the construction of an offshore structure.

2.6 REVIEW OF RECENT APPLICATIONS FOR SITE INVESTIGATION SURVEY LICENSE

In a decision from May 18th, 2023, the Government has paused the assessment and determination of existing consent applications relating to prospective ORE site investigation activity, and no new applications will be accepted by consenting bodies, until the ORE Designated Areas, which will be designated according to legislative provisions for Designated Maritime Area Plans (DMAPs) in the Maritime Area Planning (MAP) Act 2021, have statutory effect.

For the purpose of determining the commonalities on types of surveys and proposed techniques and instruments among ORE Site Investigation survey, a total of 60 applications for license to carry out surveys were analysed in this study. The information was taken as published by the Department of Housing, Local Government and Heritage's (DHLGH) Foreshore License Unit (FLU) and available in their website[1, 2] . Of these applications:

- 4 are indirectly related to ORE developments (cable laying or other infrastructure)
- 2 relate to wave energy converters and 54 refer to offshore wind developments
- 35 remain in the early stage of processing (Applied)

[1] https://www.gov.ie/en/foreshore-notices/, last consulted in the period July-August 2023.

[2] Note that from July 17th, 2023, new licenses must be submitted to the newly created Maritime Area Regulatory Authority (MARA).

- 21 have progressed to Consultation (including the 4 not directly ORE)
- 4 have received a Determination

In addition, preliminary plans for a state led Site Investigation Survey to inform a future Designated Maritime Area Plan (DMAP) have also been analysed.

Although it is almost certain that many of these applications will not progress into actual surveys being carried out, mainly due to the current transition to a plan-led ORE development approach, this analysis revealed that nearly all planned site investigations generally include the four main types of surveys discussed in sections 2.2 to 2.5, in varying degrees, and plan to employ similar equipment in each of them.

The following section contains a summary of the findings with respect to survey technologies and instruments, based on which the study proceeded to review known and eventual impacts of these technologies on fish and shellfish (Section 4 onwards). A detailed list of FLU applications consulted in this study can be found in "Appendix 2 – Details of recent Foreshore License applications for Site Investigation Survey".

2.7 SUMMARY OF SURVEY TECHNIQUES AND CHARACTERISTICS

The following table lists the technologies and typical instruments commonly used in site investigation surveys for ORE developments, along with some technical characteristics, where available and applicable (for details on acoustics and units, see "Appendix 1 – Basics of ocean acoustics"). When not explicitly stated otherwise, sound pressure levels (SPL) in decibels are referenced to 1 μPa @ 1 m (see Appendix 1 and the Glossary). See also the "Notes to the Table" and the introduction in Section 4.1 for a definition of some elements present in the table (e.g., impulsive versus non-impulsive sources).

Table 2.1 – Summary of acoustically active marine survey equipment, including mechanical sources (adapted from Ruppel *et al*, 2022; checked and complemented with information from vendors and manufacturers)

Marine Acoustic Source	Transmission Frequency	Source Level (dB re 1 µPa @ 1 m) [a]	Type/ Directionality [b]	Max Pulse Duration (ms) [c]	Min. Ping Repetition Rate (s) [d]	Example System(s)	Planned in surveys described in FLU applications [e]
AIRGUNS, MARINE VIBRATORS							
Single airgun	15-60 Hz	216–235 [f]	I, O	Few ms	>5	Sercel 105/105 in³ GI-Source gun; Teledyne Bolt airguns up to 250 in³	Maybe [g]
Airgun arrays	15-60 Hz	228–259 [f]	I, D	Few ms	>5	Multiple GI-Source or other airguns	No
Marine vibrator	5-100 Hz	unknown	N, O/D	5000	10	Vibroseis experimental source	No
HIGH-RESOLUTION GEOPHYSICAL (HRG) SOURCES							
Boomer (seismic)	300-3000 Hz	185-207	I [h], D	0.6	0.167	Applied Acoustics S-boom	Yes
Sparker (seismic) [i]	300-1400 Hz	185-226 [f]	I, O	3	0.25	Applied Acoustics Delta Sparker, SIG ELC sparker	Yes
Bubble gun (seismic)	20-2000 Hz	194-220	I, D	1.6	0.125	HMS-620	No
SUBBOTTOM PROFILERS (SBP)							
Hull-mounted	3.5, 12 kHz	199-232	N, D	64	1	Knudsen 3260 (4 4 array)	Yes
Shallow-towed [j]	0.5-24 kHz	146-180	N, D	9	0.125	Edgetech 512i, Edgetech 424	Yes
Parametric [k]	1-115 kHz	206-247	N, D	2.5	0.025	TOPAS, Innomar systems	Yes
HYDROGRAPHY							
Multibeam echo- sounder (MBES)	12-600 kHz	175-245 l	N, D	100	5	Kongsberg EM122, EM302, EM710, Reson 7160, ME70	Yes
Sidescan sonar (SSS)	65-500 kHz	196-224	N, D	0.4-1.6 [m]	0.013 [m]	L3 Klein 5000, Edgetech 4200	Yes
BIOLOGICAL ACOUSTICS – FISH FINDING SONARS							
Split beam echosounder (sonar)	18-333 kHz	212-229	N, D	8	1	Simrad EK60/80	No
Industry fish finder	14-220 kHz	< 200-210	I, O/D	Varies	Varies	Simrad SC90, ST90, SN90, SX90	No
OCEANOGRAPHIC ACOUSTIC INSTRUMENTS							
ADCP	38 to >300 kHz	211-227	N, D	37	1	Teledyne RD Workhorse	Yes
Scientific sonar (split beam)	Up to 1000 kHz	210-220	N, O/D	0.1 - 1	1/30 - 100	Bio-sonics DT-X Extreme	No
COMMUNICATION / TRACKING INSTRUMENTS							
Acoustic locators (pingers)	12-40 kHz	177-192	N, O/D	22	Varies	Edgetech CAT, Benthos UAT-376	Yes
Acoustics releases	8-34 kHz	184-192	N, O	Varies	Varies	Edgetech 8242, Sonardyne 7410	Yes
Underwater tracking systems	10-35 kHz	187-203	N, O/D	300	1	Applied Acoustics 1162, Ed-getech 4380	Yes
GEOTECHNICAL EQUIPMENT [n]							
Cone Penetration Testing	-	118-145	C, O	-	N/A	ROSON, Manta, G-Tech GT25, Fugro SeaCalf, Cambridge in-situ HDP95	Yes
Borehole	600 Hz -50 kHz	146-190	C, O	-	N/A	API drill string, Geobor "S", Fugro C25	Yes
Vibrocores	50 Hz	180-190	C/N, O	-	N/A	Fugro HPC, OSIL VC	Yes

NOTES TO THE TABLE:

- [a] Source levels (SL) taken from manufacturers' specifications, research literature, and sense-checked against information in circa 60 Site Investigation License applications. The reported source levels often do not specify peak, peak-to-peak, RMS, or any other method that was used to determine the pressure. When not explicitly stated, SPL is assumed to be RMS.
- [b] All sources except from Geotechnical Equipment are intermittent (non-continuous); there is no clear agreement on the definition of impulsive (I) versus non-impulsive (N) sources, but seismic sources (the top two classes in the table) are generally considered impulsive. C denotes continuous sources, D denotes directional, and O indicates omnidirectional sources. O/D indicates that some versions of the sources may be either omnidirectional or directional, depending on the configuration or manufacturer.
- [c] Maximum pulse duration (length) varies for different instruments in each class.
- [d] Minimum repeat rate is provided for estimating pulse exposure duration and duty cycle. Generally, the combinations of maximum pulse length and minimum repeat rate are not practical in field operations and are provided here for estimating the largest duty cycle that might be expected.
- [e] As determined from the analysis described in section 2.6. Most applications are cautious and refer to multiple instruments of the same type, in case higher-resolution or range must be achieved once on site. This does not necessarily mean that the instrument, although "planned for use in the survey", will actually be used.
- [f] Peak SL. The highest sparker value is for a 6 kJ sparker.
- [g] Only one survey out of 61 analysed (the state led survey to inform a DMAP in the SE coast) mentioned the possible use of an airgun system, as a backup and in case there is a need to acquire higher resolution data.
- [h] Some researchers have interpreted boomers as non-impulsive, but regulatory authorities have designated them as impulsive.
- [i] For sparkers operating only up to 12 kJ. Larger SL and different characteristics will apply to sparkers operating up to 40 kJ.
- [j] Some towed SBPs have substantially higher SL and should be evaluated independently.
- [k] Parametric SBP parameters taken from the manufacturer's literature.
- [l] The high SPL value in this range correspond to MBES specifications for deep ocean research (depths > ~2000 m). A more typical value for maximum SPL for MBES in shallow to medium depth waters is 215 dB.
- [m] SSS operate at a wide range of frequencies, often higher than 180 kHz. The pulse width is for the lowest frequency of SSS operation. The minimum repetition cycle is not compatible with the maximum pulse width.
- [n] It should be noted that geotechnical survey equipment produce sound only while the mechanical components of these systems are operated (e.g., hammering, vibrational or rotational drilling or similar). The source levels of these systems are in the same order of magnitude of busy commercial shipping lanes and are usually disregarded as having any potential effects for local marine life during a survey. This should not be confused with the higher source levels of piling and drilling operations during engineering work for installation of marine infrastructure, which are subject to compulsory mitigation measures.

3 COMMERCIALLY IMPORTANT MARINE SPECIES IN IRELAND

3.1 GENERAL DESCRIPTION (MAP BASED)

The identification of the most commercially important marine species (fish and shellfish) in Ireland was achieved in a sequential process. In the first step, data was downloaded from public databases available at ICES, CSO and SFPA. The data was analysed and cross-checked, and further, more detailed data was requested from SFPA. In a second step, a list of the 10 most significant species by weight (tonnes) per ICES region around Ireland was prepared using data from ICES and from SFPA and compared again. This comparison revealed some inconsistencies and gaps in the ICES data, for example, data are missing in certain years for some species. Additionally, the SFPA data underwent validation by members of the ORE Seafood Subgroup and despite exhibiting some variability, particularly in the case of landings by value data, it remained the most comprehensive dataset available. For this reason, SFPA data were used to produce the maps in this section and to inform the list of species of interest for the study. The following maps are based on data of landings (tonnage) by Irish Vessels per ICES area in Ireland provided by SFPA.

The maps shown in Figure 3.1 Figure 3.2 were produced by calculating the top 10 species landed (tonnes) in Irish waters by Irish vessels for each year (2018, 2019 and 2020), as well as the total landings for the three years combined. The proportion of the top 10 Irish species (by weight) are represented in pie charts for each ICES Area to show the variability between regions.

The colours of the species used in the pie charts (below) were standardised across the years to facilitate interpretation. Some variability in the top 10 species between years is seen in certain areas. For example, in the 27.7.b and 27.7.j.2 ICES areas, boarfishes appear in the top 10 list in 2020 only.

The maps shown in Figure 3.3 and Figure 3.4 were produced by calculating the top 10 species landed (tonnage) in each ICES Area in the years 2018, 2019 and 2020, as well as the total landings for the three years combined. The majority of the top 10 species are consistent across the years for most of the ICES areas. However, there is some variability. For example, in the case of European Sprat in the 27.6.a area, this species was recorded as the fourth most abundant species in 2019 and 2020, which is in contrast to the absence of records in 2018. Another outlier can be found within ICES area 27.7.j.2, where the European anchovy was the species with the second highest landing in 2020, but there were no landings recorded in 2018 or 2019. In the 27.7.b ICES area, European sprat was the third and fourth most fished species in 2019 and 2020 respectively, but there is no record of its landings in 2018. In this same region, Blue whiting is present in 2018 and 2019 as the third and fifth most abundant species but was not fished in significant quantities in 2020.

To capture a more comprehensive picture of the species composition in each area and to minimise any impact of the interannual variability in the tonnage landed for each species (as observed in previous maps) in the selection of relevant species for the study, the combined landings (tonnage) from 2018 to 2020 in each ICES area were computed for the top 20 species. The maps represented in Figure 3.5 show the result. In this case, it is important to note that the colour coding for species on each map is not uniform across the different regions. Therefore, it is crucial to bear this in mind when interpreting the maps. Atlantic Mackerel emerges as the prevailing species in the 27.6.a and 27.7.b areas, while the 27.7.a area is dominated by edible crab. Conversely, the 27.7.j.2 and 27.7.g areas showcase a diverse array of species.

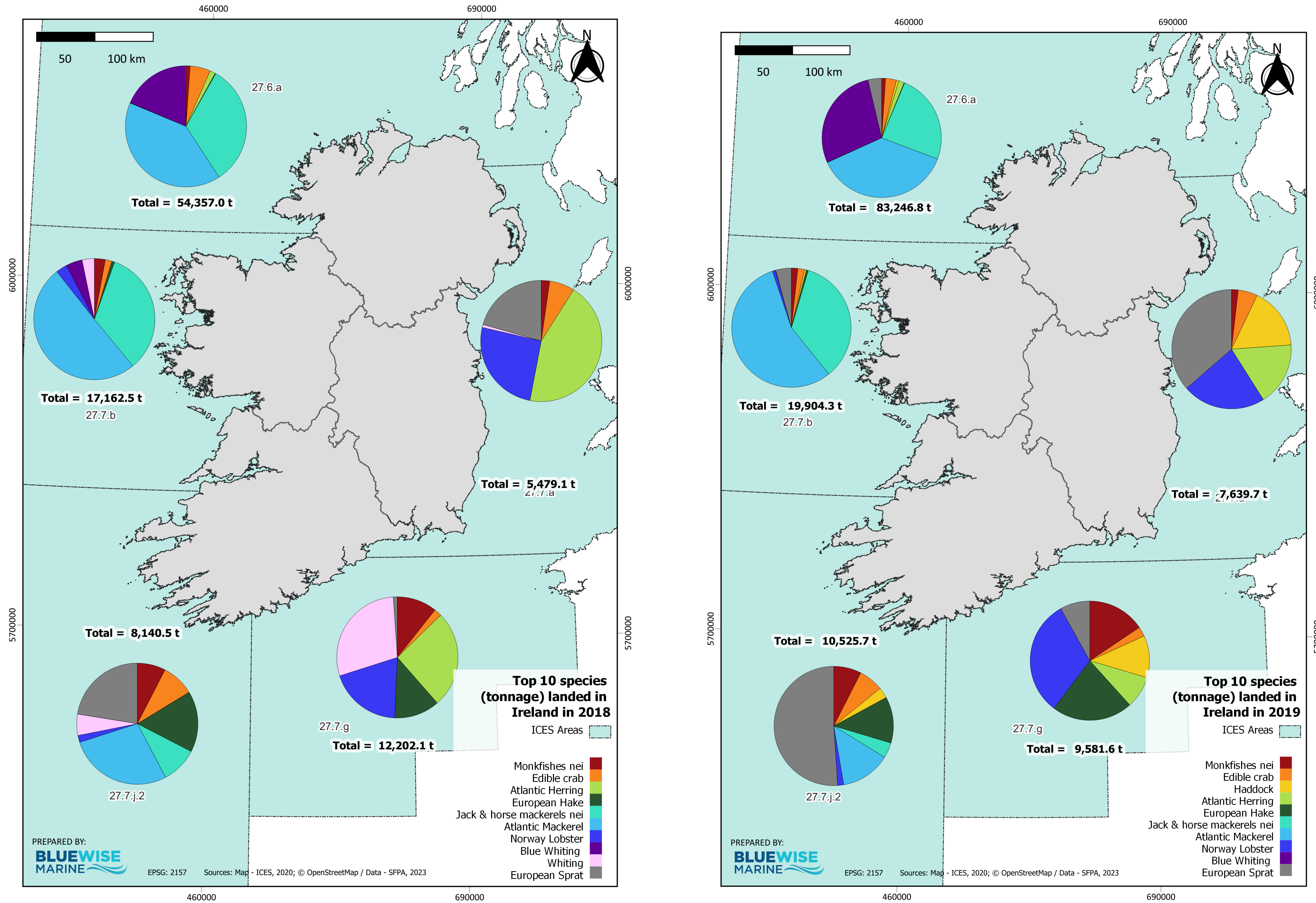
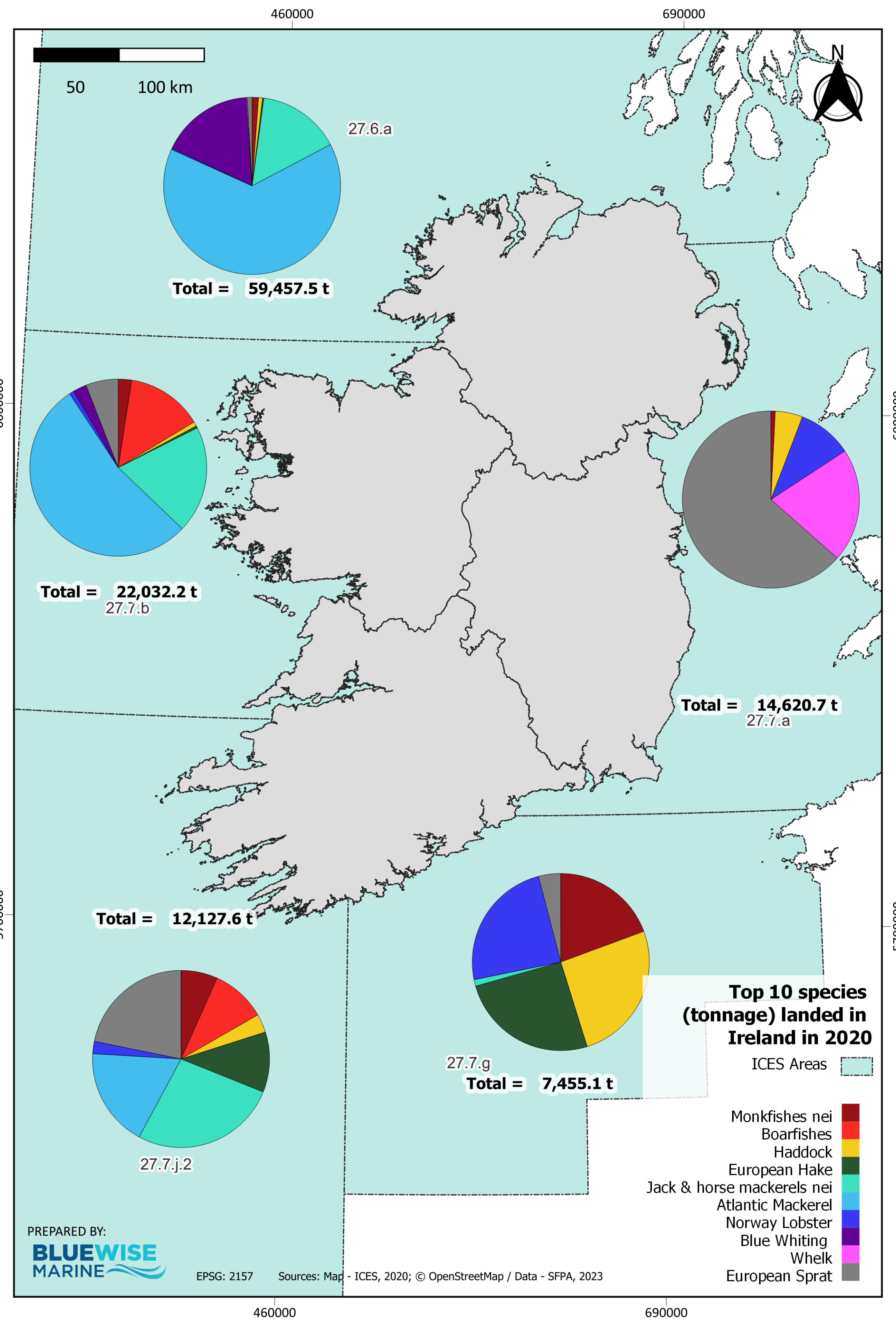


Figure 3.1 - Maps of the top 10 species landed (tonnage) in 2018 (left) and 2019 (right) in Irish waters by Irish vessels.



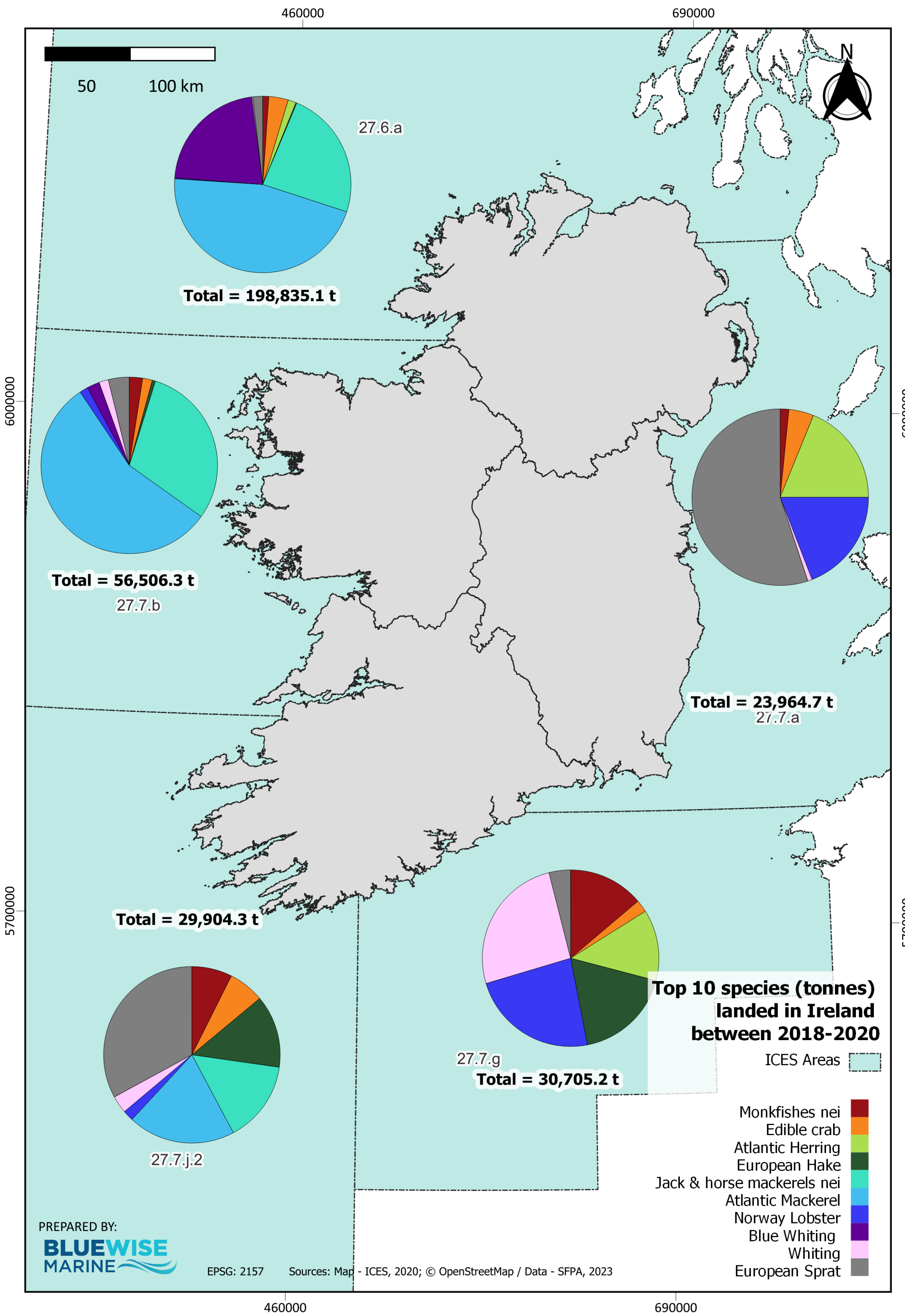


Figure 3.2 - Maps of the top 10 species landed (tonnage) in 2020 (left) and the total between 2018-2020 (right) in Irish waters by Irish vessels.

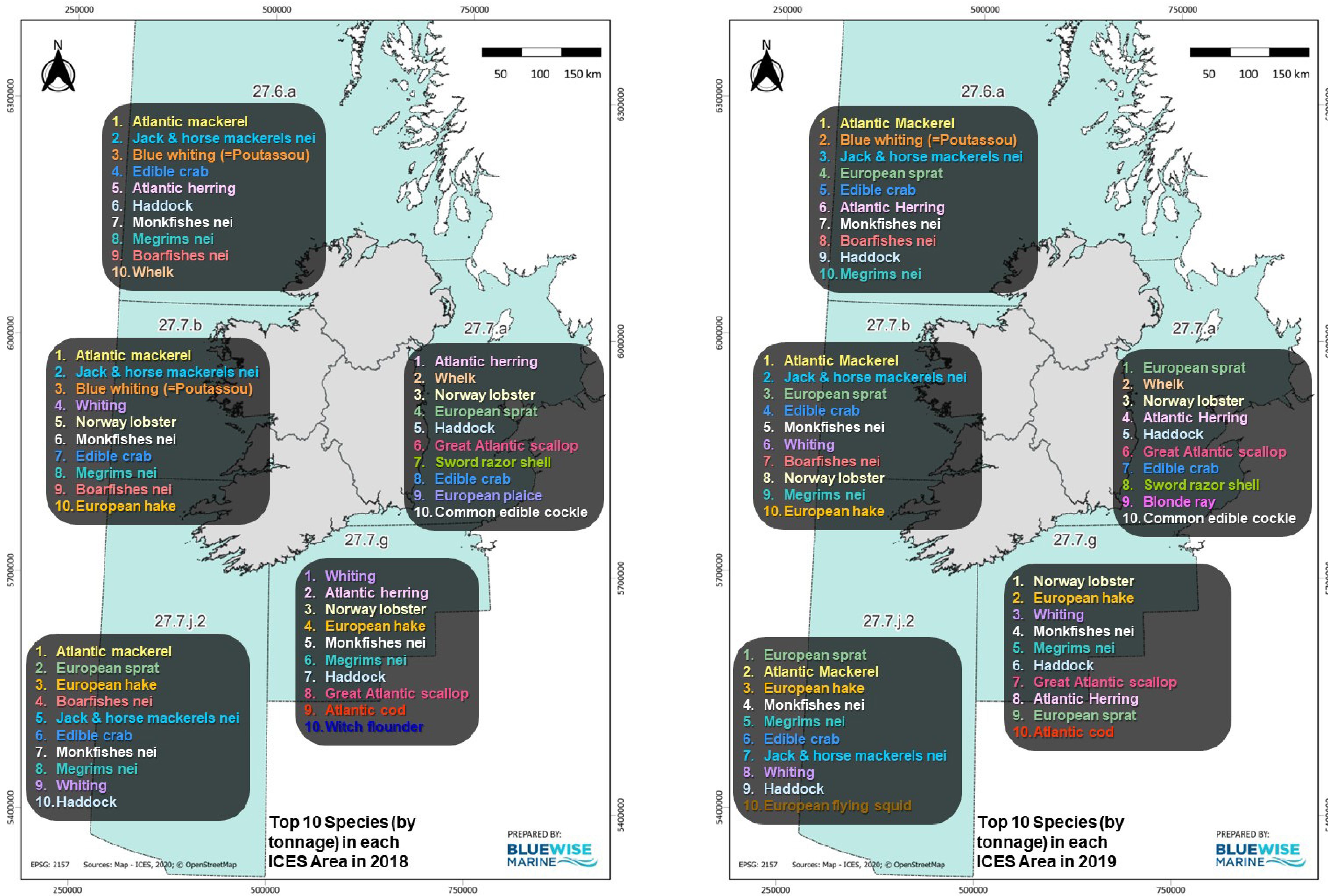
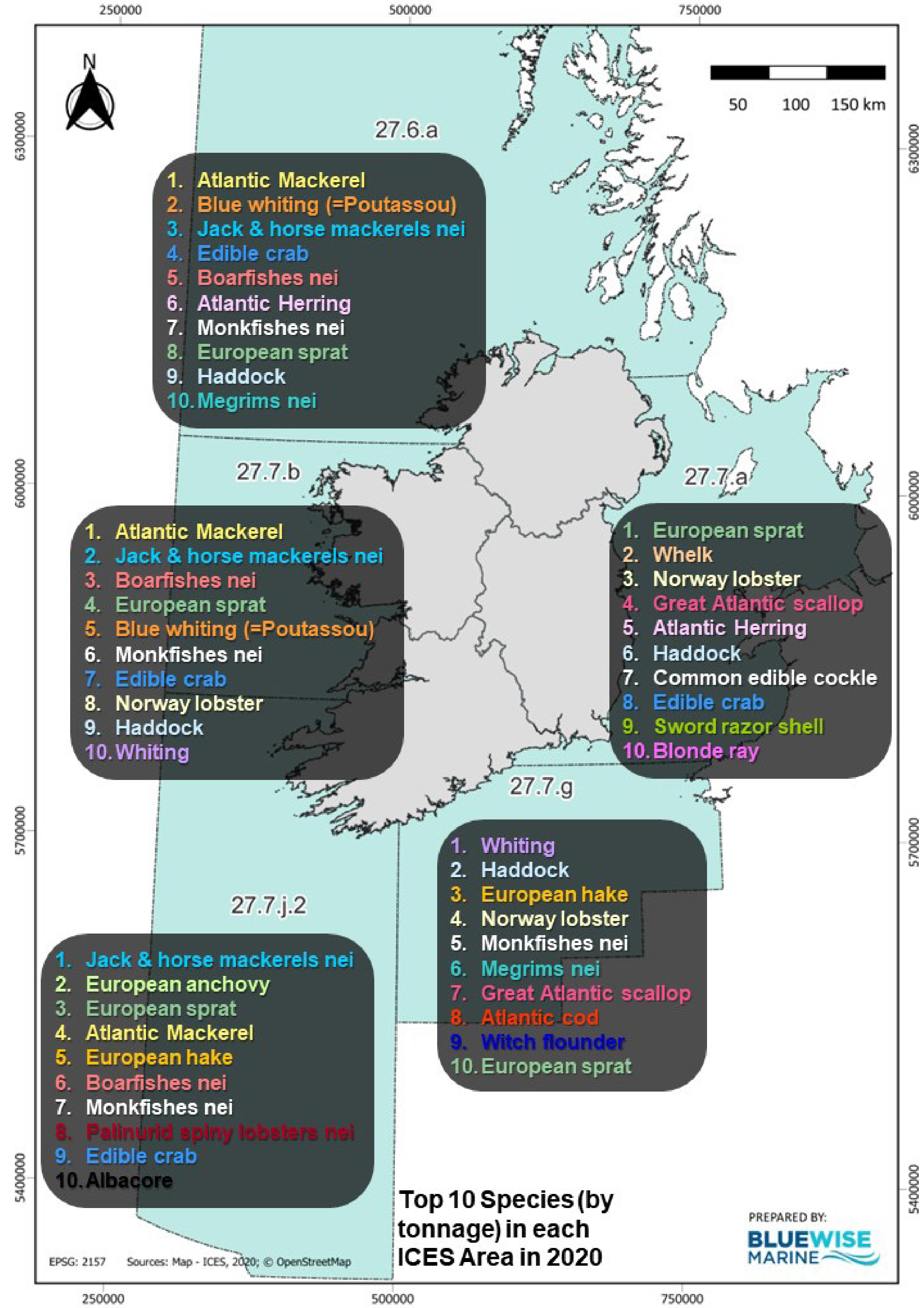


Figure 3.3 – Maps of the top 10 species landed (tonnage) in 2018 (left) and 2019 (right) in each ICES area by Irish vessels.



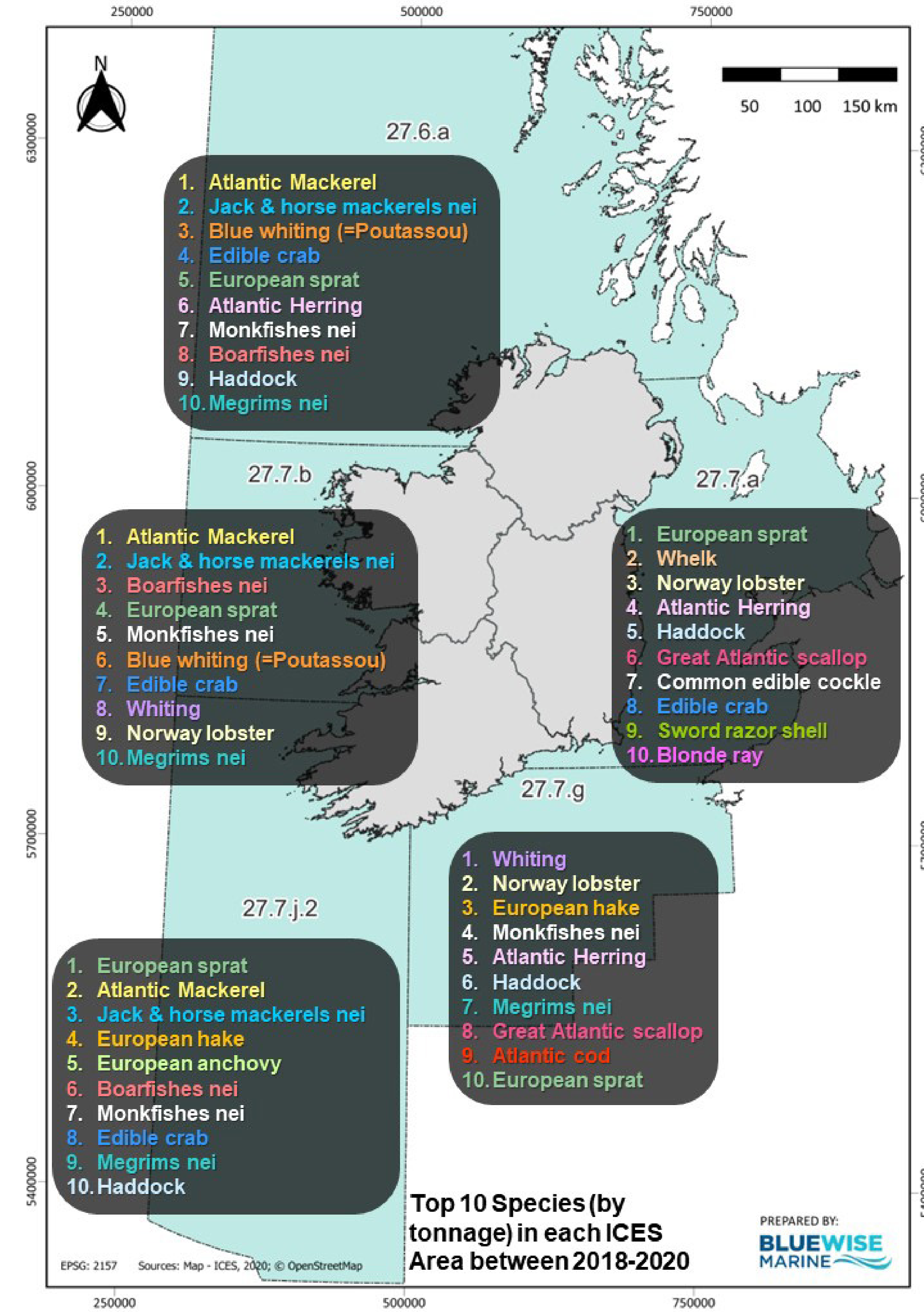


Figure 3.4 - Maps of the top 10 species landed (tonnage) in 2020 (left) and the total between 2018-2020 (right) in each ICES area by Irish vessels.

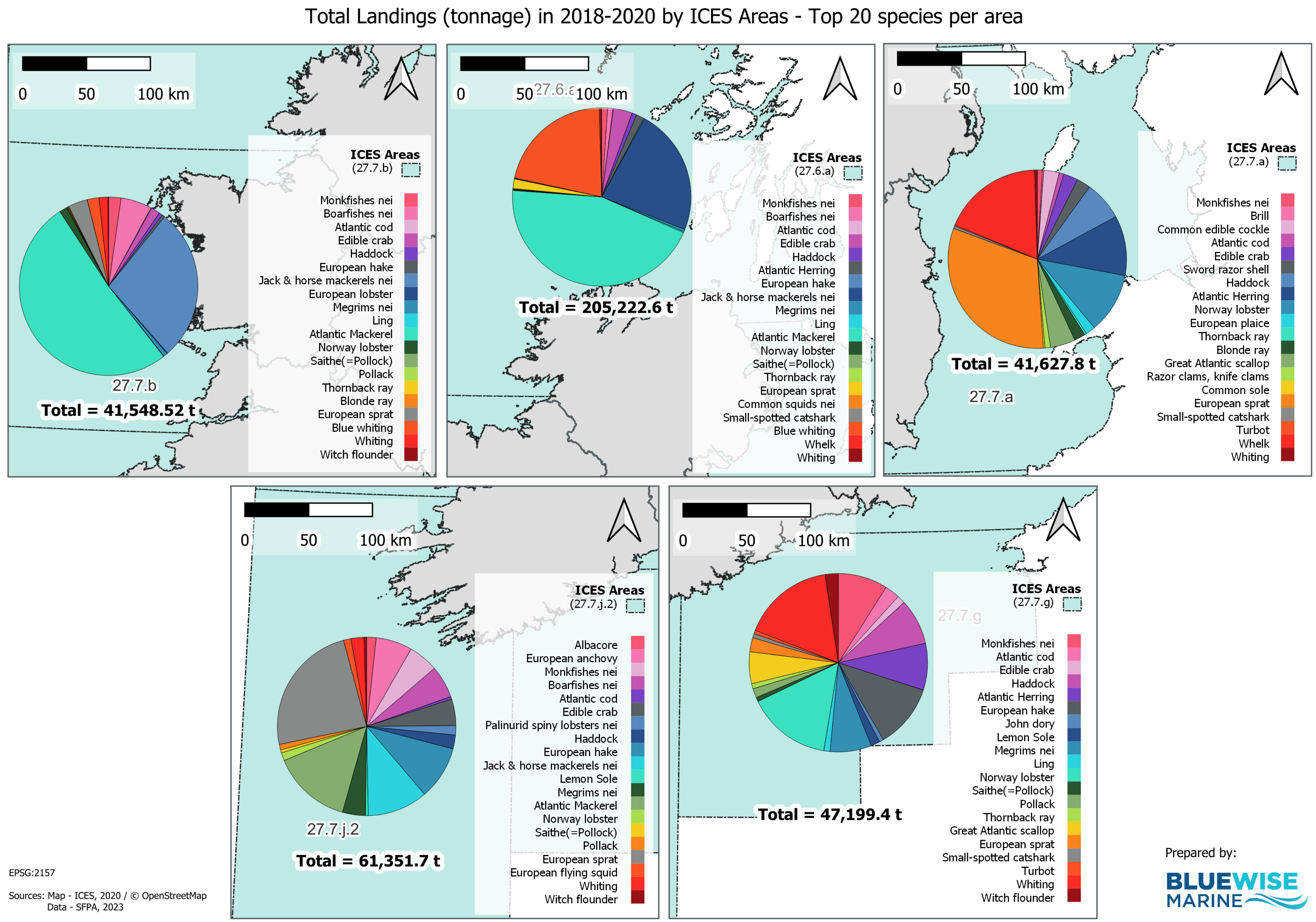


Figure 3.5 - Maps of the top 20 species landed (tonnage) between 2018-2020 (right) in each ICES area by Irish vessels.

The landings by value from SFPA data from 2018 to 2020 were also checked. Table 3.1 shows the 20 species with highest value for each year. This list of species was compared to the top 20 landings by weight by year from the same dataset. The values coloured in blue in Table 3.1 indicate the absence of that species in the top 20 list by weight in that year. No major differences were found in the species composition of both lists (although there are differences in their relative positions), with the exception of European flying squid, European lobster, John Dory, Pollack and Turbot, which were only present in the list by value, indicating that they are not landed in high quantities but have a high market value.

Table 3.1 – Value of the Top 20 species landed in Irish waters by Irish vessels for each year.

Species	2018	2019	2020
Monkfishes nei	11,070,958	12,927,155	12,428,095
Atlantic cod	2,368,402	2,024,109	1,744,912
Atlantic Herring	13,625,340	4,812,350	576,787
Atlantic Mackerel	23,051,501	138,842,871	40,881,907
Blue whiting (=Poutassou)	8,579,414	6,954,237	3,257,063
Common sole	**1,282,084**	**1,883,008**	1,490,756
Edible crab	12,379,641	10,775,810	6,012,062
European flying squid	-	**289,866**	**1,897,417**
European hake	8,360,032	10,645,149	8,926,427
European lobster	**1,665,741**	**2,271,684**	**1,596,474**
European sprat	-	3,382,370	3,042,444
Great Atlantic scallop	9,612,327	15,829,238	17,148,194
Haddock	5,444,200	6,302,646	6,222,054
Jack and horse mackerels nei	56,151,439	14,821,739	10,785,405
John dory	-	**1,223,713**	-
Lemon Sole	1,248,572	**1,203,005**	-
Megrims nei	6,926,540	7,862,555	5,580,954
Norway lobster	26,690,092	30,564,254	19,410,607
Crayfish nei	-	-	25,158,986
Saithe	**1,145,771**	-	-
Sword razor shell	2,426,183	**1,966,507**	**1,678,529**
Turbot	**1,972,563**	**2,334,625**	**1,317,524**
Whelk	4,612,832	5,604,087	4,990,746

Native oysters and bottom mussels are two fisheries not recorded in the SFPA datasets analysed above but that were highlighted as significant in the ORE development context by Teresa Morrisey, a member of the ORE Seafood Subgroup. Figure 3.6 shows the distribution of Fishery Orders (which relates mainly to native oysters) and seed mussel beds throughout Ireland's coast (data from 2020 to 2022). Fishery Orders are mostly present in inshore regions and have no close interaction with ORE projects. However, several of the seed mussel beds utilised by the fishing industry on the east-south coast overlap with some of the ORE announced projects with filed site investigation applications (see section 2.6), requiring further consideration of potential impacts.

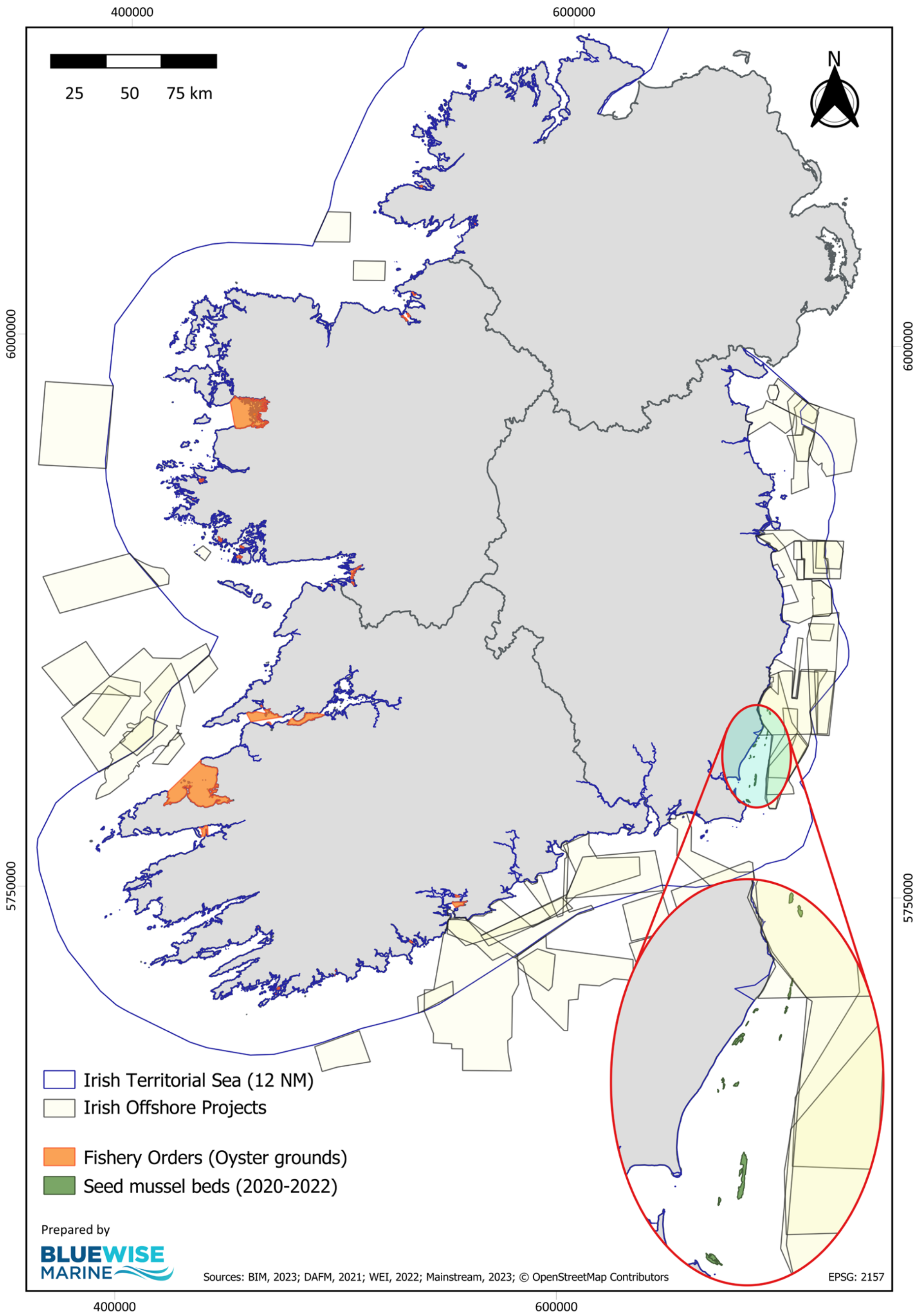


Figure 3.6. Location of Fishery Orders and Seed mussel beds in Irish Waters, 2020 to 2022.

3.2 LIST OF SPECIES FOR THE STUDY

As seen in section 3.1, there is spatial and inter-annual variation in the most commercially important species across the different Irish waters. Given this variation, the diversity of fish and shellfish species captured in Irish Waters and the expected difficulty in finding specific information on eventual impacts of sound for all of them, the species of interest were organised into seven study groups for the purposes of this study. These groups are as follows:

- 1.Generalist Fish
- 2.Specialist Fish
- 3.Decapod Crustaceans
- 4.Gastropods
- 5.Elasmobranchs (Sharks, Rays, and Skates)
- 6.Bivalves
- 7.Cephalopods

Generalist fish are defined as having no swim bladder or a small swim bladder, that generally cannot hear sounds above 1 kHz, with SPL thresholds as high as 120 dB re 1 μPa @ 1 m (hereafter dB, see "Appendix 1 – Basics of ocean acoustics" for details on units). This means these fish can only hear very loud sounds and are mostly sensitive to particle motion only. ***Specialist*** fish are traditionally defined as fish with well-developed swim bladders connected to the hearing system (mechanically or otherwise) and allows them to hear sounds up to several kHz and much lower SPL thresholds. A combination of the lateral line and the ear allows hearing specialist fish to detect both sound pressure and particle motion at low frequencies (<100Hz, or even infrasonic <20 Hz down to 5 Hz) and at ultrasound frequencies (between 20 kHz and 150 kHz), with relatively low thresholds.

Popper and Fay (2011) claimed that the specialist-generalist dichotomy was overly simplistic and proposed a continuum of sound detection from motion detection only (generalists) on one end to extensive use of pressure (specialists) on the other. This spectrum was divided into five distinct categories (Popper *et al.*, 2014), and has been applied in other studies (Popper and Hawkins, 2019):

- 1. Fish lacking swim bladders that are sensitive to a very narrow band of sound frequencies (up to 500 Hz). They are also sensitive to particle motion.

- 2. Fish with swim bladders that do not contribute to hearing. These fish are sensitive to a narrow band of sound frequencies and to particle motion.

- 3. Fish with swim bladders that are close but not connected to the ear. They are sensitive to a wider band of sound frequencies (up to 500 Hz), and particle motion.

- 4. Fish that have morphological structures connecting their swim bladders to their ears. They are primarily highly sensitive to sound pressure but can still detect particle motion. They can detect a much wider band of frequencies (up to several kHz).

- 5. Eggs and larvae.

For the purposes of this report, groups 1 and 2 are considered generalists, and groups 3 and 4 are considered specialists. These groupings result from the relative paucity of literature regarding the impacts of noise available on the identified commercially relevant fish especially the near total lack of papers on particle motion. The general categorization into generalists and specialists aligns with the level and detail of information available, and well as the frequencies and intensities of sound emitted by relevant survey techniques.

The landings by weight from SFPA data for 2018 to 2020 (used to prepare the illustrative maps in the preceding section) were compared to the landings by value from the same dataset, as explained further above. The merging resulted in a preliminary list with 37 species, which was presented to the ORE Seafood subgroup, for discussion and validation. Based on this work, the 37 most commercially important fish and shellfish species in Ireland (2018 to 2020) have been allocated to the **seven study groups** as shown in Table 3.2.

The list of key species and study groups presented in Table 3.2 guided the literature review presented in section 4 (Review of effects and impacts).

Study Group	Key Species
1.Generalist Fish (Low Sound Sensitivity)	Horse Mackerel Mackerel Megrim Monkfish Witch Flounder Plaice Sole Turbot
2.Specialist Fish (High Sound Sensitivity)	Boarfish Haddock Hake Herring Ling Saithe Sprat Whiting Blue Whiting Cod Albacore John Dory
3. Decapod Crustaceans	Brown Crab European Lobster Nephrops Crayfish (Palinurids) Green crab Velvet crab Spider crab
4. Gastropods	Whelk
5. Elasmobranchs (Sharks, Rays and Skates)	Small-Spotted Catshark Thornback Ray Blond Ray
6. Bivalves	Cockle Razor Clam Scallop Seed Mussel
7. Cephalopods	Common Squids European Flying Squid

Table 3.2 – Allocation of key commercially important fish and shellfish species to seven study groups.

4. REVIEW OF EFFECTS AND IMPACTS

4.1 INTRODUCTION

As seen in Section 2, the vast majority of instruments for surveying in the ocean use or emit some form of acoustic energy when acquiring different types of data and samples. Therefore, this section will focus on the effects of underwater sound on marine life[3].

Sound in the ocean can be used in one of two ways: actively or passively. Active instruments generate sound that, after propagation in the medium, is received at the listening component of the instrument and processed for data (e.g., MBES, SSS, USBL, and many others). Passive instruments only listen to sound generated elsewhere, and do not generate any sound. Thus, any potential impact of sound from site investigation surveys is due to the active instruments eventually being used, as they comprise a sound source, each with its own characteristics in terms of power emitted, frequency or frequency bands used, and duration and form of sound pulses.

In general, sound in the ocean can be further distinguished between continuous and intermittent. Continuous sound sources introduce acoustic energy in the medium more or less continuously over a long period of time; examples of continuous anthropogenic acoustic noise are sound generated by underwater machinery in continuous operation, or the aggregated sound of shipping in a busy navigation corridor. On the other hand, intermittent sound sources inject acoustic energy in the medium in relatively short pulses (up to several seconds). Intermittent sources can be impulsive (pulse duration in the order of a few milliseconds) or non-impulsive (longer pulse durations). Examples of intermittent sources are most, if not all, active marine surveying equipment, or mechanical sources of noise such as pile driving or drilling. In practical terms, the duty cycle of intermittent sources (i.e., the relation between the duration of the pulse and the interval between pulses) is also important, since repeated pulses with short interval in between may lead to more severe impacts than the individual pulses.

When studying the effects of sound on marine life, it is important to distinguish between continuous and impulsive sources, as the

[3] Other equipment that uses mechanical actuators in geotechnical surveys, such as VC, boreholes or CPT, produce vibrations that ultimately also cause propagation of sound. Note also that some modern equipment use light at small absorption wavelengths (e.g., blue light is used for underwater communications), but the effects of this on marine life are not known. In general, any optical sensors, such as those in sediment cages, have no impact on marine life due to the small distances travelled by the emitted light.

effects will necessarily vary. A low-power source can have significant effects if the sound is continuous, whereas even a high-power source emitting a short burst of sound can have limited or no significant effect on marine life. A useful acoustic parameter that accounts for this is the Sound Exposure Level (SEL), which considers both power and duration of the sound (see "Appendix 1 – Basics of ocean acoustics" for details, and section 5 "Discussion of impacts").

Another important aspect is the frequency at which sound is emitted (or received), since different animals perceive sound in different ways – some more, some less, others not at all, each with their own hearing threshold and range. Low-frequency sounds are generally taken as those with frequencies below 500 Hz – 1 kHz, high-frequency sounds above 10 kHz. It has become commonly accepted that, for those species whose audiogram (hearing thresholds as a function of frequency) is known, sounds with frequencies outside their auditory range or with sound pressures below their hearing threshold do not cause physical harm or significant impact to the individual (e.g., Dooling, Leek and Popper, 2015), because either the sound is not perceived by the hearing systems, or the sound is too weak to be discriminated above ambient noise. This may need to be reviewed in the future under the light of recent research highlighting the role of particle motion and of the increasing levels of continuous anthropogenic ambient noise (Popper and Hawkins, 2019; Cox et. al., 2018).

Finally, and as already mentioned in the text, research on impacts of sound has traditionally focused on SPL, possibly because it is a property easily measured with a single hydrophone and is the most notorious in the case of the most powerful instruments producing higher SPLs, such as airguns (single or arrays) and other instruments used in HRG surveys (seismic surveys). In fact, a quick inspection of Table 2.1 reveals that nearly all scientific instruments used in site investigation surveys other than boomers and sparkers typically produce lower SPL than airguns, especially in shallow waters and intermediate depths when they are used with lower emitted power. Studies on impacts have a particular focus on the impact of airguns (or similar equipment).

The review of effects and impacts of sound on fish and shellfish began with an analysis of review papers on this subject; research papers of this type provide a general and summarised overview of findings and are a good introduction to the problem. The following are existing literature reviews that discuss the current (at year of publishing) research and gaps on the impacts of marine survey noise on fish and invertebrates:

- Impacts of geophysical seismic surveying on fishing success (Hirst and Rodhouse, 2000).
- A critical review of the potential impacts of marine seismic surveys on fish and invertebrates (Caroll et al., 2016).
- Sound the alarm: A meta-analysis on the effect of aquatic noise on fish behaviour and physiology (Cox et al., 2018).
- Population-level consequences of seismic surveys on fishes: An interdisciplinary challenge (Slabbekoorn et al., 2019).
- An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes (Popper and Hawkins 2019).

Each of these review papers highlight and classify the impacts that seismic and geophysical surveys, as well as other high intensity sound sources, may have on fish and marine invertebrates, and the impact categories in Table 4.1 and Table 4.2 further below were synthesised from these papers, particularly Caroll et al. (2016). Each review highlighted several notable knowledge gaps in the available literature, and while this review incorporates findings from papers up to 2022, many of the research gaps noted in these reviews have still not been filled.

Based on these literature reviews, the study progressed with a search for more details on specific impacts. Firstly, a list and description of the potential impacts of low frequency sound on fish and marine invertebrates as a result of geotechnical and geophysical surveys was created, which was followed by an overview of each impact. Finally, a systematic search for details on each impact steered by the list of species of interest and informed by the review papers was carried out. The scientific literature databases Web of Science, Google Scholar, Tethys, and Research Gate were accessed in June 2023 with the following search string: ALL=(((Marine AND Life) OR Fish* OR Crustacean* OR Elasmobranch* OR Shark* OR Gastropod* OR Bivalve* Or Cephalopod* NOT Mammal* NOT Cetacean* NOT Whale* NOT Dolphin*) AND (Pressure OR Intensity OR Source Level OR Hearing OR Frequency OR Impact) AND (Survey* AND (Geophysical* OR Geotechnical))).

The papers this search string produced were reviewed for relevance with Web of Science returning 19 papers, Google Scholar returning 33, Tethys returning 1, and Research Gate returning 3. These papers were reviewed in depth and citations in key review papers such as Caroll et al., 2016 were reviewed and added to the database if relevant. These papers were collated into a spreadsheet and summarised with key information highlighted. From this spreadsheet, summary tables of impacts were generated (Table 4.1 and Table 4.2). The gaps in each table were queried and, where possible, papers were sourced with information to fill those gaps. By the end of the review process, 77 papers had been sourced and reviewed, with 56 of them being summarised in the spreadsheet, and 44 of those papers being used to construct the summary tables. The results of the extended review of studies that examined those impacts can be found in section 4.2 for fish, and in section 4.3 for marine invertebrates.

4.1.1 Physical impacts

Air Bladder Damage – Air (or swim) bladders contain gases and when damaged or ruptured by marine acoustic noise, particularly particle motion caused by acoustic waves, can lead to barotrauma. Fish with air bladders connected to their ears are most prone to this damage. Invertebrates do not have air bladders (Caroll et al., 2016).

Otolith/Statocyst Damage – Otoliths are calcium carbonate structures within the ears of fishes. They contribute to the senses of gravity and linear motion of fishes and if damaged can result in reduced fitness as a fish's sense of balance and direction is compromised. Statocysts are sensory receptors in some invertebrates, notably including crustaceans, bivalves, and cephalopods, that perform an analogous role to otoliths in vertebrates in that they allow for the perception of gravity and acceleration.

Organ/Tissue Damage – Sensory cells in the ear can be damaged by prolonged periods of high-intensity, low-frequency sound which can cause a permanent loss in hearing, a permanent threshold shift (PTS), or more commonly a temporary loss in hearing, a temporary threshold shift (TTS). Loss in hearing can reduce fitness as the ability to detect sounds made by predators, prey, or the environment are reduced.

Mortality/Abnormality – Exposure to high energy impulsive sound, such as air gun arrays or pile driving, can cause damage to internal organs, particularly swim bladders (see above), kidney, liver, and intestines. Exposure at very close vicinities to the source can cause mortality.

4.1.2 Behavioural impacts

Startle Response – Startle responses are brief responses to sudden stimuli and are not generally considered particularly detrimental to animals.

Sound Avoidance – Sound avoidance can manifest as moving, often to greater depths, to avoid the source of sound, changes in schooling patterns, or changing swimming speeds. Habituation over time can reduce or eliminate sound avoidance behaviours.

Auditory Masking – Auditory masking occurs in situations where noise levels are higher than the normal ambient levels and animal auditory behaviours are affected due to their reduced ability to detect normal sounds because of increased noise levels. Predator avoidance may be reduced in cases of TTS or PTS, but auditory masking of predator sounds due to marine noise can also reduce the awareness and thus avoidance of predators by prey animals.

Foraging – These are the behaviours associated with the search for wild food resources. Disrupted foraging behaviours as a result of marine noise can reduce the fitness of animals as their energy budgets' efficiency will be reduced.

Reproduction – Intraspecific audible communication can be masked by low frequency noise. Species that use audible communication as part of mating behaviours can be disrupted.

Bioturbation – Bioturbation is the reworking of sediment by organisms. Common forms of bioturbation include burrowing, ingestion of sediment, or sediment reworking via defecation of sediment grains.

Attraction – In some circumstances, animals may be attracted to sound sources, often either due to mistaking the sound source, out of curiosity, or associations with the sound source (e.g., sharks associating vessel noise with food in areas with shark ecotourism).

4.1.3 Physiological impacts

Metabolic rates – Affected metabolic rates can be measured in changes to ventilation rates, respiration, and food consumption.

Stress bio-indicators – This can be measured through an increase in primary stress hormones such as adrenaline and cortisol in vertebrates, and increases in glucose, heat-shock proteins, lymphocytes, and stress hormones in the haemolymph of invertebrates. Stress bio-indicators may also be indicative of impacts on immune responses.

Metamorphosis/Settlement – The development, settlement, and habitat selection of fish and invertebrate larvae may be affected by low frequency sound.

4.1.4 Other

Catch rates/abundance: Each of the above potential impacts may impact the catch rates of fish and shellfish. While changes in catch rates will not reveal the specific impacts that have led to the reduction, and other factors not related to the acoustic disturbance may be at play as well, they are the most direct means of observing whether a population has been impacted. Conversely, although laboratory-based studies are very valuable as they enable direct observation of impacts, they are considered limited as they cannot perfectly match in situ conditions (see also section 5 "Discussion of impacts").

4.2 KNOWN EFFECTS OR IMPACTS ON FISH

Table 4.1 shows the results of the literature review on impacts of sound on fish. The table should be interpreted with reference to the descriptions of impacts in the subsections below.

4.2.1 Physical impacts

Adult and juvenile fish and their eggs have been shown to experience mortality in the immediate vicinity of airgun array detonations, typically within a few tens of metres and at sound levels close to 240 dB or more, while at lower levels (down to 180 dB) physical impacts include inner ear damage, haemorrhaging, eye damage, blindness, swim bladder rupture and eventually death (Hirst and Rodhouse, 2000)[Ref.3]. Specialist fish are considered more prone to damage and mortality at greater distances, whereas demersal fish (generalists) have not shown signs of significant impact after the deployment of airguns. For example, the study by Meekan et al., (2021)[Ref.4] showed that emperor fish and brownstripe red snapper (generalist fishes) were not significantly affected after being exposed to airgun deployments (<100 Hz from 228 dB to 247 dB). McCauley et al., (2003)[Ref.9] showed long term or permanent damage to the sensory epithelia of pink snapper, a specialist fish, as a result of exposure to airguns up to 100 m away (20 – 100 Hz at 25 dB above ambient sound levels). Similar damage, and damage to swim bladders, was observed in seabass and tilapia (specialist fishes) due to exposure to pile driving noise at similar intensities to airguns, 210, 213, and 216 dB (Casper et al., 2013) [Ref. 17]. Kane et al., (2010) [Ref. 8] studied the impacts of exposure to high-intensity sonar (198 dB at 170 – 320 Hz and 210 dB at 2.8 – 3.8 kHz) on Channel catfish, a specialist fish with an auditory system connected to the swim bladder, and rainbow and hybrid sunfish. No exposure-related pathologies were observed when tissue was examined post-exposure to high-intensity sonar.

	Generalist Fish (Low Sound Sensitivity)			Generalist Fish (Low Sound Sensitivity)							Elasmobranchs
Physical											
Air bladder damage	Ref. 3	Ref. 4		Ref. 3	Ref. 9	Ref. 17		Ref. 8			
Otolith/statocyst damage	Ref. 3	Ref. 4		Ref. 3	Ref. 9	Ref. 17		Ref. 8			
Organ/tissue damage	Ref. 3	Ref. 4	Ref. 16	Ref. 3	Ref. 9	Ref. 17		Ref. 8			
Mortality/abnormality	Ref. 3	Ref. 4	Ref. 16	Ref. 3				Ref. 8			
Behavioural											
Startle response	Ref. 6			Ref. 34							Ref. 28
Sound avoidance	Ref. 6			Ref.13	Ref.22	Ref.25	Ref.34	Ref.10	Ref.33	Ref.36	Ref.38
Foraging				Ref.5				Ref.13			
Reproduction				Ref.37							
Bioturbation											
Auditory Masking				Ref.2			Ref.18		Ref.28		
Attraction											Ref.27
Physiological											
Metabolic rates				Ref.34				Ref.35			
Stress bio-indicators				Ref.31		Ref.37		Ref.35			
Metamorphosis/settlement	Ref.16			Ref.7							
Catch Effects											
Catch rates/abundance	Ref.4	Ref.26	Ref.43	Ref.3			Ref.26		Ref.1	Ref.43	

Table 4.1 – Summary of the observed impacts of low-frequency sound on fish. The numbers in the table refer to a specific scientific paper in which certain impacts were observed and are superscripted in those citations below.

Key:

- Response at Realistic Exposure Levels from sources not commonly used in Site Investigation Surveys
- Response at Unrealistic/Unknown Exposure Levels
- No Response
- Possible response/conflicting or anecdotal results
- No data
- Not applicable

Andriguetto-Filoha et al. (2005) [Ref. 15] detected no significant negative impacts to Australian artisanal fish exposed to airgun noise. Bolle et al. (2012) [Ref. 16] observed no significant increase in morality in common sole larvae exposed to high noise levels, but stressed that their results cannot be extrapolated to the larvae of other fish species.

4.2.2 Behavioural impacts

Stimpert et al., (2019) [Ref. 6] measured the impacts of autonomous underwater mobile survey vehicle (AUV) noise on Pacific rockfish and found that while there was an increase in noise over ambient levels from 99 +/-3 dB at 50 – 500 Hz to 105 – 112 dB, the majority of the sound energy was from the navigation and communication instruments of the vessel and out of the expected sensitivity ranges for the rockfish, which did not react to the increased sound energy in the area.

Studies have shown that low frequency noise can cause avoidance behaviour in fish, although the degree of impact varies on a species-by-species basis. In a lab-based experiment, Atlantic cod showed significant avoidance behaviour to low-frequency sound (130 – 140 dB at 25, 50, 90, 125, and 250 Hz); however, the stimulus was not strong enough to make all individuals avoid the sound (Mueller-Blenkle et al., 2008) [Ref. 10]. In another study, cod displayed avoidance behaviour to the split-beam echosounders of bottom-trawling vessels, with changes in both horizontal and vertical movement speeds observed (Handegard et al., 2003)[Ref. 25]. Avoidance in Atlantic cod is not consistent across studies as shown by McQueen et al., (2022) [Ref. 32], in which tagged cod did not avoid airgun noise several kilometres away (source exposure level ~145 dB) while in their spawning grounds. In marine settings, the typical behaviours that are observed in schooling fish include swimming to the bottom of the water column and swimming faster in tighter groups (Fewtrell and McCauley, 2012; Davidsen et al., 2019) [Ref. 22,31]. These behaviours are sometimes coupled with increased startle responses such as the study by Fewtrell and McCauley (2012)[Ref. 31] in which trevally, pink snapper and squid showed significant increases in such behaviour when exposed to airgun noise between 147 and 151 dB, whereas Davidsen et al., (2019) [Ref. 34] observed similar changes in movement patterns in Atlantic cod and saithe at 121 to 163 dB, but without startle responses.

The effects of disrupted movement due to avoidance of marine survey sound can affect diurnal activity cycles and reduce foraging efficiency, as was observed in Atlantic cod exposed to an airgun array at 40 – 400 Hz and a cumulative sound exposure level of 186.3 dB over 3.5 survey days (van der Knapp et al., 2021) [Ref. 5]. In European seabass, the impacts of air guns (200 – 1000 Hz at 180 – 192 dB) seem to be stronger at night, suggesting that the impacts of marine surveys on fish may be more severe at different times depending on the species (Neo et al., 2018) [Ref. 36]. Sound avoidance, and reduced hearing thresholds as a result of exposure, could also weaken the ability of juvenile fish to find preferred habitats (Caiger et al., 2012) [Ref. 7].

In addition to avoidance behaviours, a common impact of marine noise is auditory masking in which the introduction of noise above ambient levels makes it more difficult for animals to hear important sounds in the environment, particularly predators, prey, and intraspecific communication (Caroll et al., 2016) [Ref.49]. Airgun noise (22 – 88 Hz at 127 dB) has been shown to mask sound for Atlantic cod up to 11 km away (Pine et al., 2020) [Ref. 2]. Auditory masking has been observed in damselfish, brown meagre, and red-mouthed goby (species that communicate audibly) in experiments in which they were exposed to vessel noise playbacks at 136.5 dB (Codarin et al. 2009) [Ref. 18].

While research on sound avoidance is more common, there have been studies, particularly on pelagic sharks, that show an attraction to low frequency sound (25 – 1000 Hz at 20 dB above ambient levels), although that attraction is tempered by startle responses to sudden changes in the sound (Myrberg Jr. et al., 1972, 1978) [Ref. 27,28].

Studies on the impacts of marine surveys on elasmobranchs (sharks, rays, and skates) have been extremely limited to date. Mickel et al. (2020) [Ref. 38] created a behavioural audiogram of southern stingrays and demonstrated that they react to sound in the frequency range from 50 to 500 Hz, at intensity levels of 140 dB for females and 160 dB for males. These reactions included changes to swimming behaviour, including increased swimming time and decreased resting time, as well as increased surface breaches and side swimming (Mickel et al. 2020) [Ref. 38].

4.2.3 Physiological impacts

It has been shown that fish can display elevated stress responses as a result of increased marine noise. European seabass in a lab-based experiment were exposed to playbacks of seismic surveys at 130 and 140 dB and responded with elevated ventilation (Radford et al., 2016) [Ref. 31]. Habituation was observed, however, and the stress responses diminished to the point that there were no differences in stress, growth, or mortality between the exposed fish and a control group after 12 weeks of exposure (Radford et al., 2016) [Ref. 31]. Studies on Atlantic cod have shown that seismic airgun noise (121 to 190 dB) can affect energy budgets (Hubert et al., 2020) [Ref. 35], cause reduced heart rates in response to particle motion (Davidsen et al., 2019) [Ref. 34], and a mild cortisol increase, which in cases of chronic exposure can significantly reduce reproduction and fertilisation rates during spawning seasons (Sierra-Flores et al., 2015) [Ref. 37].

There are concerns that exposure of fish larvae to high levels of low-frequency sound will negatively impact larval development or related behaviours, as seen in the impacts on habitat selection by pink snapper (Caiger et al., 2012) [Ref. 7] (see also section 4.3 on invertebrate larvae). However, the larvae of common sole, a generalist, have been shown in a lab-based experiment to be largely unaffected by the deployment of laboratory-based sound playbacks at 50 – 1000 Hz from 186 to 210 dB (Bolle et al., 2012) [Ref. 16].

4.2.4 Other impacts

Reports on the impacts of low-frequency sound on the catch rates of fishes vary. Short term reductions in catch of herring, cod, and salmon (all specialists species), have been observed during and after seismic surveys using airgun arrays at SPL in the range 240 – 265 dB (Hirst and Rodhouse 2000) [Ref. 3]. Conversely, in generalist demersal fishes such as emperor fish and brownstripe red snapper, there were no signs of significant decline during or after airgun deployment (Meekan et al., 2021) [Ref. 4]. Løkkeborg et al., (2012) [Ref. 26] observed variance in catch rates across different fishing gear types after airgun exposure. Gillnet catches of redfish and halibut increased, while longline catch rates for halibut and haddock decreased. There have also been reports of bottom trawl catch rates increasing in the vicinity of seismic surveys (Gausland, 2003) [Ref. 43]. This would indicate that the impacts of low frequency sound on catch rates are complex and vary across both gear type and species.

4.3 KNOWN EFFECTS OR IMPACTS ON SHELLFISH, GASTROPODS, AND CEPHALOPODS

Table 4.2 shows the results of the literature review on impacts of sound on shellfish, gastropods, and cephalopods. Table 4.2 should be interpreted with the assistance of the descriptions of impacts in the subsections below.

4.3.1 Physical impacts

Invertebrates are generally considered less vulnerable to sound exposure than fish due to their lack of swim bladders or other gas filled chambers. Lobsters and benthic molluscs have been observed to have survived airgun exposure unharmed less than 2 m from the source (Hirst and Rodhouse, 2000) [Ref. 3].

	Decapod Crustaceans			Gastropods	Bivalves		Cephalopods	
Physical								
Air bladder damage								
Otolith/statocyst damage	Ref.15	Ref.29	Ref.41				Ref.14	Ref.11
Organ/tissue damage	Ref.15	Ref.29	Ref.41					
Mortality/abnormality	Ref.15	Ref.29	Ref.41		Ref.39	Ref.44		
Behavioural								
Startle response	Ref.19		Ref.24		Ref.12			
Sound avoidance	Ref.20						Ref.22	
Foraging	Ref.42							
Reproduction								
Bioturbation	Ref.20		Ref.42					
Auditory Masking								
Attraction								
Physiological								
Metabolic rates					Ref.39	Ref.44		
Stress bio-indicators	Ref.23	Ref.40	Ref.29		Ref.30	Ref.39		
Metamorphosis/settlement					Ref.13			
Catch Effects								
Catch rates/abundance	Ref.3		Ref.33				Ref.3	

Table 4.2 – Summary of the observed impacts of low frequency sound on marine invertebrates. The numbers in the table refer to a specific scientific paper in which certain impacts were observed and are superscripted in those citations below.

Key:

- Response at Realistic Exposure Levels from sources not commonly used in Site Investigation Surveys
- Response at Unrealistic/Unknown Exposure Levels
- No Response
- Possible response/conflicting or anecdotal results
- No data
- Not applicable

On the other hand, invertebrates may be more susceptible to physical damage by the particle motion component of sound or have their sense of direction (vertical) affected by it. Statoliths are structures in some marine invertebrates, including cephalopods and crustaceans, that fill the same role of detecting kinetic sound components as otoliths. There is conflicting data in lab based cephalopod studies on whether exposure to high-intensity low-frequency sound (10 to 200 Hz at 122 dB, or 50-400 Hz at received levels of 175 dB_{PEAK}) can damage the sensory hair cells of statocysts after at least 12 hours of exposure and more (Kaifu et al., 2008, André et al., 2011) [Ref. 11,14]. In the latter study, octopuses were unrealistically kept at relatively short range from the source during the experiments.

Exposure to airgun noise (180 and 190 dB) has been shown to increase mortality in scallops (Pecten fumatus), especially over a chronic timescale, but this mortality is not beyond naturally occurring mortality rates (Day et al., 2017) [Ref. 39]. On the other hand, lower SPL caused by piling or drilling (such as those used in VC or CPT survey techniques) have been shown to cause no effect on Pecten maximus (scallop) postlarvae in tank simulations carried out by Olivier et al., (2023) [Ref. 44], who suggest that their findings underscore the relevance of the frequency composition of the soundscape over source levels.

4.3.2 Behavioural impacts

Continuous low-frequency impulsive noise has been shown to repress movement, burying, and bioirrigation behaviour in Dublin Bay prawn (Nephrops norvegicus) during exposure to continuous sound at 135 – 140 dB and impulsive sound at 150 dB from 100 Hz to 2 kHz (Solan et al., 2016) [Ref. 20].

In a lab-based experiment in which green crabs (Carcinus maenas) were exposed to ship noise playback (received SPL of 148 – 155 dB, 0.2 – 3 kHz) the eating behaviours, but not food detection, were disrupted. Predator detection and responses were not reduced compared to controls, but retreats to shelter were slower (Wale et al., 2013) [Ref. 42].

Fewtrell and McCauley (2012) [Ref. 22] showed that squids engage in similar avoidance behaviours to fish in response to airgun deployments (120 to 184 dB), moving deeper in the water column, swimming faster, and grouping more tightly.

Scallops have been shown to flinch in response to airgun exposure (180 and 190 dB), and the rate of their recessing reflex increased during exposure (Day et al., 2017) [Ref. 39].

4.3.3 Physiological impacts

There are very few high-quality data on the physiological impacts of marine noise on marine invertebrates, but current evidence suggests that physiological responses to particle motions are the most common (Edmonds et al., 2016) [Ref. 41]. European spiny lobsters exposed to boat noise playbacks (120 – 130 dB at 100 to 1000 Hz, and 110 to 130 dB at 1 – 20 kHz) in a lab-based experiment showed significant changes to locomotive behaviour and haemolymphatic parameters, with increased glucose, proteins, Hs70 expression, and THC which are all stress bio-indicators (Filiciotto et al., 2014) [Ref. 23]. A subsequent study by Celi et al. (2015) [Ref. 40] noted that these effects on stress bio-indicators can compromise immune responses in this species, reducing its fitness. Exposure to very high low-frequency sound levels (202 to 227 dB) did not damage American lobsters, but did seem to cause organ stress and sub lethal effects on feeding and serum biochemistry (Payne et al., 2007) [Ref. 29]. In lab-based experiments, the natural valve periodicity of blue mussels (Mytilus edulis) was disrupted by low-frequency vibrations (5-410 Hz, PVL about 94 dB to 126 dB re 1 nm/s) which may have implications on their fitness (Roberts et al., 2015) [Ref. 30].

The density of haemocytes (blood cell equivalents) in the haemolymph of scallops was reduced by exposure to airgun noise, which compromised their metabolism and immune systems (Day et al., 2017) [Ref. 39].

The larvae of bivalves may be affected by low-frequency noise. In a lab-based experiment on the New Zealand scallop by de Aguilar de Soto et al. (2013) [Ref. 13], exposure to seismic survey playbacks at 3 second intervals (165 dB (RMS) per pulse, up to 90 hours of exposure) showed developmental delays and the development of abnormalities after 24 hours, which became more significant as exposure continued, particularly in the early stages of development (i.e., D-veliger stage). The larvae were kept very close to the sound source, though (5 – 10 cm), in a relatively small tank (2 x 1.3 m cylinder), in a setup that hardly represents survey conditions.

Another study (Olivier et al., 2022) [Ref. 44] on the early stages of development of bivalve, performed in more realistic conditions, found that the shell growth rate in post-larval scallops increased when subjected to pile driving noise with SPL up to 188 dB (SEL 215 dB over 24 hr) with a duty cycle of 6 hours on / 6 hours off, for several days, and the same happened for drilling noise with SPL up to 176 dB (SEL 222 dB over 24 hr) with a duty cycle of 19 hours on / 5 hours off. In both experiments, there was no significant mortality observed.

4.3.4 Other impacts

Studies on the impacts of airgun deployments on catch rates of decapod crustaceans indicate that they are unaffected (Hirst and Rodhouse, 2000 [Ref. 3]). Parry and Gason, (2006) [Ref. 1] did not detect impacts on catch rates of Australian rock lobsters, although the sensitivity of their analysis was limited by the low levels of seismic surveying in the study area. Morris et al., 2018 [Ref. 33], in their study to examine whether snow crab catch rates were affected by seismic surveys (sound levels in the range 155 – 163 dB), found that there were no effects in the short term, and suggested that if seismic effects do exist in this species, they are smaller than changes related to natural spatial and temporal variation.

5 DISCUSSION OF IMPACTS

5.1 SPATIAL AND TEMPORAL EXTENSION OF KNOWN IMPACTS

The preceding section describes the results of an extensive review of existing literature on the impacts of marine surveys (mostly high resolution geophysical or seismic surveys) on fish and shellfish.

As pointed out throughout that section, the findings from research have been achieved under more or less severe conditions or assumptions, which impose limits on their interpretation. For instance, only a few studies were actually carried out in situ, during or after surveys took place, with proper controls before and after the surveys; many studies were done in the controlled environment of a laboratory, in tanks, in which the simulations can be affected by undesired factors, sometimes without the researcher being aware.

Nevertheless, in the absence or impossibility to perform in situ studies, results obtained in the lab are important in the sense that they can indicate whether there is some impact of the sound produced, even if the SPL or SEL threshold obtained in lab is not realistic or representative of real ocean and real survey conditions.

Noticeable features of the literature review are the disparity in results from research, which sometimes seem contradictory or counter-intuitive, and the significant gaps in knowledge that still persist, adding to the difficulty in interpretation and synthesis.

With the above in mind, highlighting a summary of possible impacts from site investigation surveys, as well as possible sources, has been prepared in Table 5.1 for each group of species of interest in this study, based on the findings in section 4.

Table 5.1 – Study groups and key species of interest, observed impacts resulting from noise sources in research and possible impacts from surveys.

Study group	Species	Observed impacts documented in research	Experimental sound source	Possible source(s) in surveys
Generalist Fish (Low Sound Sensitivity)	Horse Mackerel Mackerel Megrim Monkfish Witch Flounder Plaice Sole Turbot	No significant impact found to date in research. Temporary change in behaviour	Low frequency Airgun noise	Airgun / airgun array
Specialist Fish (High Sound Sensitivity)	Boarfish Haddock Hake Herring Ling Saithe Sprat Blue Whiting Whiting Cod Albacore John Dory	Physical: Air Bladder Damage, Otolith Damage, Organ/Tissue Damage	Low Frequency Airgun Noise	Airgun / airgun array
		Behavioural: Sound Avoidance, Foraging, Reproduction, Auditory Masking	Low Frequency Airgun Noise	Airgun / airgun array
			Lab-Based Playback of 120 dB Noise, repeated impulsive noise, Ship noise	Geotechnical and geophysical surveys, survey vessel noise
		Physiological: Metabolic Rates, Stress Bio-Indicators, Metamorphosis/Settlement	Lab-Based Playback of 120 dB Noise, pile-driving noise, linear sweeps	Geotechnical and geophysical surveys, survey vessel noise
		Catch Effects: Catch Rates/Abundance	Low Frequency Airgun Noise	Airgun / airgun array
		Physiological: Metabolic Rates, Stress Bio-Indicators, Metamorphosis/Settlement	Lab-Based Playback of 120 dB Noise, pile-driving noise, linear sweeps	Geotechnical and geophysical surveys, survey vessel noise
		Catch Effects: Catch Rates/Abundance	Low Frequency Airgun Noise	Airgun / airgun array
Decapod Crustaceans	Brown Crab European Lobster Nephrops Crayfish (Palinurids) Green crab Velvet crab Spider Crab	Behavioural: Startle Response, Sound Avoidance, Bioturbation	Lab-Based Playback of pure noise, pile-driving noise	Geotechnical surveys, survey vessel noise
		Physiological: Stress Bio-Indicators	Lab-Based Playback of vessel noise	Vessel noise

Table 5.1 – Study groups and key species of interest, observed impacts resulting from noise sources in research and possible impacts from surveys.

Study group	Species	Observed impacts documented in research	Experimental sound source	Possible source(s) in surveys
Gastropods	Whelk	No studies currently available on this group	-	-
Elasmo-branchs (Sharks, Rays and Skates	Small-Spotted Catshark Thornback Ray Blond Ray	Behavioural: Startle Response, Sound Avoidance, Attraction	White Noise Generators	Geotechnical surveys, vessel noise
Bivalves	Cockle Razor Clam Scallop Seed Mussel	Behavioural: Startle Response	Lab-Based Playback of low frequency Airgun noise	Airgun / airgun array
		Physiological: Metabolic Rates, Stress Bio-Indicators, Meta-morphosis/Settlement	Lab-Based Playback of pile-dri-ving and drilling noise plus shaker to cause particle motion (a ≤ 0.55 ms-2)	Geotechnical surveys, borehole
Cephalopods	Common Squids European Flying Squid	Physical: Statocyst Damage	Lab-Based Playback of sinusoidal wave sweeps 50 – 400 Hz	Geotechnical surveys, Vibrocore, airgun / airgun arrays (distance depen-dent)
		Behavioural: Sound Avoidance	Low frequency airgun noise	Airgun / airgun array

Important notes to the table:

1) Table 5.1 represents a simplified assessment of the most likely source of impacts for each study group, based on the most likely instrument(s) capable of producing similar sound characteristics to those used in research (which may be unrealistic, as discussed in sections 4.2 and 4.3). Actual impacts will depend on other factors that have not been considered in the preparation of the table and that vary from case to case, such as distance to source, duty cycles of the survey equipment, sound exposure level, etc.

2) The colour codes used in the table highlight that the possible impacts are either: i) **unlikely** (in grey), due to the specific instrument(s) not being used in site investigation surveys; ii) **possible** (dark yellow), due to the instruments being planned for use in site investigation surveys or; iii) **likely** (light yellow), due to causes not just specifically accountable to site investigation surveys.

5.2 UNKNOWN POSSIBLE IMPACTS

The extrapolation of know impacts (i.e., those that have been documented in lab or in situ studies) into real life applications presents several challenges. The following are some of the most relevant:

- **Biases.** There was a marked early tendency of the first studies to focus on certain species, which have become more well represented than others. This may cause biases in the interpretation of results, especially if those results are used in extrapolations to other species and constitutes, in itself, a limit in the extent to which realistic extrapolations can be made. Likewise, due to the scarcity of studies in many species, lack of significance and difficulty in reproducibility, the ratio of "impact" to "no impact" may not be representative (e.g., if one study finds that cod are sensitive to airgun exposure, this does not mean that all surveys with similar SPL will affect cod in the same manner). There are also noticeable knowledge gaps, particularly in elasmobranchs and gastropods. It may be misleading to assume that each species in a given group would have the same reaction (this is reflected in the tables). This means that it is very difficult to predict with a high degree of confidence what the impacts on a species that has not been studied will be.

- **Sensory capability of fish**. Fish have usually been categorised into generalists and specialists concerning their earing ability. As research progresses, this division is showing to be overly simplistic and reductive. Fish sense the environment in multiple ways, and it has been shown that the role of the swim bladder in the hearing process depends on the species: in some it has absolutely no role in the auditory system, while in others the swimming bladder contributes to the hearing process, even if not connected to auditory systems (Sand, 2023). Hence, the “generalist to specialist” division, rather than binary, is actually more like a spectrum or range, with fish showing capabilities that place them somewhere between the two extremes. From the literature review, it is believed that the categorisation adopted in the study (section 3) may induce the reader in thinking that the commercially important Irish “specialist” species are in the high-end of earing sensitivity when, in reality, they likely belong to the middle of the spectrum. There are very few or no major Irish fisheries for species on the “specialist” end of that spectrum, which are fish with air bladders physiologically and functionally connected to auditory systems, such as goldfish and otophysan fish (Popper and Fay, 2009).

- **Constraints of laboratory experiments.** A large number of existing research is based on results obtained in the lab. Lab experiments are intrinsically limited by their dimensions. In addition to the fact that many studies are not considering particle motion at all, it is known that sound propagation in a confined tank environment misrepresents low frequency sounds (wavelengths much larger than the tank’s dimensions), distorts mid-frequency sounds (with some spectral components being completely wiped out) and suffers from reverberation of high frequency sounds due to multiple reflections in the walls (Olivier et al., 2022). Therefore, results obtained in tanks are very dependent on position of the specimen(s) relative to the sound source, since a large spatial variability can exist even for samples spaced only a few centimetres apart. On the other hand, fish in tanks cannot avoid the area as they may do in the wild, which can add to errors in the interpretation of results. However, lab-based experiments in tanks can be useful to provide insights into impacts on less mobile animals such as decapod crustaceans, gastropods and bivalves.

A research technique that tries to overcome the limitations of experiments with fish in captivity is the playback of anthropogenic noise (e.g., airguns or pile driving) in a relatively controlled environment such as fish cages held in known positions in open water, to estimate the behaviour of fish using visual observation, fishing or research sonars. These experiments provide indication of changes in behaviour, that vary with species, and some indicative SPL or SEL for generation of impact. One such experiment (Hawkins et al., 2014) suggested indirect response to sound due to food web interactions (i.e., downward motion of fish in response to observed downward motion of zooplankton related to the same sound exposure). An important conclusion of this type of studies is, on one hand, the limited or null value of studies with fish in captivity to infer absolute responses by wild fish and, on the other hand, an additional level of challenge introduced by food-web interactions and the response of the lower layers of the food chain to sound, which is basically unknown.

- **Sound levels**. Nearly every paper on the impacts on marine life focus on either airgun noise, or sound caused by activities other than marine surveys such as pile-driving or boat noise. It has become accepted that SPL above 180 dB will cause physical damage, and mortality of specialist fishes is likely for SPL higher than about 230-240 dB in the close vicinity of the source. For surveys using a single airgun or an airgun array, this would mean fish only a few tens of meters from the source could die, while fish at greater distances could suffer other impacts. Since the sound intensity decreases with the inverse squared distance, SPL is greatly attenuated at longer ranges. Most survey instruments operate at lower SPL than that of airguns and airgun arrays. The site investigation surveys being planned for ORE developments do not generally include airgun surveys, and thus should generate less sound than the typical HRG survey common in Oil and Gas exploration. Consequently, a site investigation survey not using airguns is likely to be less impactful than those using airguns.

  It should also be noted that geophysical surveys not using airguns utilise equipment that is generally very directional, which limits impacts to individuals in the immediate vicinity of the survey vessel's vertical; further afield, sound levels are greatly reduced by design. They also operate at frequencies higher than the normal hearing ranges of many fish (specialist and generalist). In line with this argument, a study of Pacific herring (Peng et. al., 2015) suggested that herring are more sensitive to the continuous low frequency noise generated by vessel traffic, for which they showed avoidance responses, then to the higher frequency pulses from sonar and echosounders. In summary, further field-based research focussed on the equipment typically used during geophysical and geotechnical surveys for ORE projects is required. Studies should also focus on the typical ranges (water depths) found at ORE sites.

- **Particle motion.** There is an increasing view that particle motion is as significant a source of impact as sound energy, but it is currently poorly studied. This would be particularly relevant to invertebrates and specialist fish (Farina, 2018). In particular, it has been shown that particle velocity is only proportionally related to sound pressure in the case of progressive plane waves (i.e., freely propagating waves). Close to the coastline or to boundaries, particle velocity may become independent of sound pressure as reflection and diffraction become much more relevant in the propagation of sound; in addition, vibrating sources induce not only sound (and sound-induced motion), but also hydrodynamic particle motion, the effects of which are predominant over those of sound pressure in the near field of the source. Lab-based experiments in fish tanks miss the particle velocity component of the impact, as sound generated in fish tanks drives acoustic pressure linearly (although complicated by the presence of walls) and the particle velocity remains improperly unexcited. Thus, the reactions of fish observed in these studies, usually accountable to a relatively high SPL, could very well be caused by much smaller PVL that remains unknown. It remains, therefore, unclear how high PVL cause impacts on fish other than behavioural. Roberts et al. (2015) examined the impacts of substrate borne vibration and particle motion on mussels by using a sediment shaker rather than sound production. This was the only study of its kind sourced in the literature review. However, there is a growing understanding of the importance of particle motion in the sound detection of fish and aquatic invertebrates, and it is possible that this will lead to more studies on this topic (Nedelec et al., 2016).

- **Sound characteristics.** Although studies of impacts of sound on marine animals tend to focus on sound pressure levels and frequencies (some also on particle motion), there are other sound characteristics important in the production of impact, especially physical impacts. Equally important are the rise time of pressure increase and the decay time of pressure decrease, in the wave oscillations (Gausland, 2003). Sound wave theory is simplified by using sinusoidal approximations to wave forms, but waveforms of real sound produced by survey equipment can be very different. Very rapid increases or decreases of pressure are more likely to produce damage or significant impact, particularly in the near field, since the hearing systems have no time to adapt, or the receiver may not be able to move away. For instance, mortality usually results from very high level sounds – SPL above 230 dB – with rise and decay times of 1 ms or less, within 5 m of the source. These conditions are achieved by explosions but not by airguns, and much less by other less powerful equipment (e.g., MBES, SBP, ADCP, boomers, sparkers). Thus, even high SPL caused by sound with slower rise and decay times are more benevolent to fish than very short, very rapid bursts of equivalent SPL sound.

- **Sound Exposure Level**. The topic of how much sound an animal can actually receive before impact is noticeable presents obvious challenges. This is important in situations where site investigation surveys may happen repeatedly in the same location. Aside from evident physical impact such as mortality of permanent changes in behaviour, which are rare, assessment of other types of impact in the presence of varying but recurrent SPL sounds (see, for instance, Table 4.1) requires intrusive analysis of the subjects (fish and shellfish), or extensive and well controlled experiments to determine whether, for example, TTS or PTS have occurred. These analyses and experiments have been carried out for a small number of species (e.g., marine mammals, cod, salmon, among others), but much more research needs to be performed on other species.

One possible way to overcome the difficulties associated with this research is to use SEL to compute the total acoustic "energy" accumulated in an individual subject to an impulsive or continuous sound. SEL, or cumulative SEL (SEL_{CUM}), has the advantage of allowing for comparison of varying SPLs and of different sound sources (see "Appendix 1 – Basics of ocean acoustics" for details on SEL). The theoretical SEL generated by site investigation surveys can, in principle, be computed from the technical parameters of the equipment being used. However, it is necessary to keep in mind the limitations and assumptions, and the exact terms in which the units for each parameter have been defined. For example, using the values in Table 2.1 for a prominent source of sound in geophysical site surveys (for instance, a high resolution geophysical survey using a sparker system at full power, with a SPL of about 226 dB, pulse length of 3 ms at the highest duty cycle theoretically possible – 4 cycles per second), the equivalent SEL is about 200 dB (single strike) and SEL_{CUM} is 206 dB in one second, or 224 dB in one minute for a static individual placed at 1 m of the source. In this time interval, the survey vessel would have moved ~125 m, assuming a survey speed of 4 knots. If we further assume cylindrical spreading of the sound (in shallow waters), the variation in SEL due to transmission loss for the same static individual in that period of time would be about 21 dB, meaning the SEL_{CUM} would vary between a maximum of 224 dB and 203 dB depending on the individual's initial position in relation to the source.

The above estimates are rough approximations of SEL for a stationary receiver, in somewhat unrealistic conditions (e.g., the sparker would not operate at full power in shallow water, and the duty cycle could be smaller – fewer pulses per second). Nevertheless, they are, in principle, comparable with the SEL used in the laboratory studies that informed some of the impacts shown in section 4. But can this comparison be made at all? The problem with such comparisons is that, although the SEL in lab are usually smaller (when computation of equivalent

SELCUM is possible or has been reported), the conditions the individuals in experiments are exposed to are very different to those found in nature (for example, individuals in lab cannot escape the tank, or are placed too close to the sound source) and, therefore, direct comparisons should be made with extreme care. In fact, records of SELCUM computed for free-ranging animals are nearly non-existent (with the exception of marine mammals).

Finally, another difficulty associated with reliable estimates of impact due to high SEL (cumulative or not) is the ability of the auditory systems of fish to recover between sound pulses, or lack thereof. If the sound pulses are spaced enough in time, this could lead to reduced perceived SEL than those computed. Unfortunately, this recovery capacity must also be highly dependent on species, and there is currently no research that can reliably indicate whether this factor is significant or not in the assessment of impacts.

- **Short term response**. In the short term, due to the mobility of fish, it has been observed that some fish move away from the sound source (avoidance of disturbance), while others move towards the source (attraction or curiosity?). Both these behaviours may result in an increase or a decrease in catches, depending on the fishing gear being used, and there's anecdotal reports of both. In the absence of carefully designed experiments and research, it is difficult to establish whether any eventual reduction in catches is due to the disturbance in habitat due to the survey, or to the reduction in stock due to fishing activity, or to fish trying to improve their chances of survival by migrating elsewhere (avoidance of survey or escaping the threat posed by the fishing activity itself).

- **Long term response**. There is a recognised huge gap in research about the long term effects of underwater noise on marine animals (e.g., Slabbekoorn et al., 2019, Popper and Hawkins, 2019), and the existing studies are often contradictory in their results and suggest responses to the acoustic disturbance that may depend on other factors as well.

The study of long term fish behaviour is particularly challenging. For instance, inferring impact on fish wellness or fitness from short-term behavioural changes due to anthropogenic noise is not recommended due to difficulty in correlating both, and to the number of uncontrolled variables. This challenge becomes eves greater if there is a physical impact but no apparent change in behaviour, as this could only be assessed with intrusive analysis of the fish or shellfish in question. Nonetheless, a few carefully designed and controlled studies, such as that reported by Meekan et al. (2021), have been made; this study, carried out before, during and after a seismic survey with airguns in Australia, found no evidence of long term impacts on several demersal fish species that could be attributed to the survey. In another study in Norway (Løkkeborg et. al., 2010), it was reported that gillnet catches of halibut and redfish increased during and after a seismic survey with airguns, while longline catches of halibut and haddock declined but later recovered a few days after the survey. These results were obtained while the survey vessel was closest to the fishing gear. On the other hand, the catch size of saithe diminished after the survey, suggesting the larger fish left the area. Both studies indicate that there is a definite impact during and shortly after the seismic surveys but suggest that (at least for the species studied) there is a tendency for recovery (likely due to habituation once the vessel moves farther away and the SPL greatly decreases). Unfortunately, neither study was carried out long enough to determine other eventual long-term effects at population level, such as delayed mortality due to unnoticeable physical damage, effects on reproduction rates, larvae mortality, etc.

Anecdotal reports by fishers or the records of landings after a site survey or an ORE development (or any development at sea, for that matter) can help identify any possible long term response, particularly habituation (i.e., the species in the area become habituated to the altered soundscape, especially if the sound source(s) are continuous or recurrent) or permanent avoidance, which would mean one or more species have left the area. However, these sources of information must be considered with care, since habituation varies across species, type of impact and timescales, and thus can be masked by other factors, such as changes in fishing effort, natural fluctuations of fish populations, presence of predators, food scarcity or abundance, or spawning habits. The temporary nature of site surveys and the dynamics of the changing ocean environment make it difficult to design and carry out studies in situ. All these factors make the identification of specific impacts from surveys very challenging unless any eventual impact is large in scale. Thus, a careful control and analysis of all pertinent factors are required, combined with more rigorous scientific data, prior to inferring conclusions from landings records or voiced reports.

Notwithstanding, researchers have tried to use landing statistics to assess long term impacts. The official records of landings were analysed in a study of catches in Norway (Vold et. al., 2012) before, during and after a seismic survey using ICES data, but it suffered from several shortfalls (e.g., coarseness of ICES data, small number of years used in the study, no results for the long-term post-survey period) and it has only confirmed what had already been observed and reported in another study by Løkkeborg et. al. (2010).

It should also be noted that other long-term impacts, such as a physical PTS, are harder to ascertain based only on analysis of long time series, as these impacts could affect only one generation on just a few individuals.

Due to the above considerations and the large variability of results across the research analysed in this study, in addition to the inherent variance and lack of reproducibility in the large majority of the research carried out to date, this study will not attempt to extrapolate from the findings in section 4 to eventual and unknown impacts, as this would mostly be educated guess work. At this point, it will suffice to highlight the necessity to undertake significantly more research on the many aspects of underwater acoustics and fish and shellfish sensory physiology, as mentioned by many experts in these fields, to realistically assess impacts of site investigation surveys on fisheries. Nonetheless, the following section discusses possible effects of surveys, and of repeated or frequent surveys, on fish and shellfish populations.

5.3 LIKELIHOOD, SPATIAL AND TEMPORAL EXTENSION OF IMPACTS

Fishers are mostly concerned with the population level effects of an intense site investigation survey effort (by one large survey, or by many, closely spaced low intensity surveys) on fish and shellfish, with possible short or longer term effect (or effects) that would immediately result in reduced catches or gradually lead to sustained reduced catches, possibly jeopardising their activity and livelihoods.

As discussed in the previous sections, a population level effect is difficult to establish. For instance, if on one hand the rare short-range mortality of a high intensity impulsive source (as seen in preceding sections, only possible at very short ranges for non-mobile animals, eggs or larvae) may not have any long-term effect in a large population, as the mortality would have to be much higher to have a significant impact on populations than that occasionally observed in research, on the other hand any unnoticeable physical impact may impair the fish or shellfish ability to reproduce, forage, or survive to predators, thus possibly impacting a population. Whether these processes could occur as a result of site investigation surveys, and to what extent, is currently poorly understood.

Notwithstanding, some research has been done recently in this topic with the assistance of Population Consequence of Disturbance (PCoD) modelling (Slabbekoorn et. al., 2019). These models are based on one of two approaches: either starting from the detailed species-specific model of all effects of sound on an individual, moving then upwards to assess effects on populations in realistic scenarios, or starting by determining an "acceptable" population level effect, then studying the extent to which the model parameters may be changed until that threshold effect is reached. Each parameter change is then compared with the known causes of effects in individuals. This approach reveals the most likely and significant pathways to reach population level effects above the threshold, and also those to which the population is relatively insensitive. It can also be used to direct research effort into improving knowledge of the required individual, less well known effects that are likely to contribute to the population level effect most significantly. Models based on the above approaches can take several forms. Models used in fisheries studies include Dynamic Energy Budget (DEB) models, in which all physiological processes consume or gain energy, and the impact of one or more disturbances on the energy flow is known, and Agent Based Models (ABM), which are similar to DEB but include the impact of physical properties of the habitat, which can affect energy budgets, and solve this for an individual – an "agent". Once the agent and its interactions with the environment are modelled, a population is computationally created with multiple similar agents. Both DEB and ABM have been developed and successfully used in estimating responses at population level in several scenarios (e.g., to estimate anchovies' growth and spawning time and duration of in response to temperature and food availability (DEB application by Pecquerie, Petitgasa & Kooijman, 2009), or estimating the impact of pile driving on the movement patterns of cod (ABM application by Rossington et. al., 2013), in which realistic bathymetry and a parabolic equations sound propagation model was coupled with a (less realistic, for simplicity) cod behaviour in response to noise at the frequency they are most sensitive to, i.e., 160 Hz).

In fact, the flexibility of ABM can be used in complex situations, such as in the effects of acoustic disturbances, by combining hydrodynamic, ecological and food web, and advanced sound propagation models. A well designed ABM can provide reliable insight into the spatial and temporal effects of single or repeated site surveys, or any marine activity generating anthropogenic sound. However, reliable field data is required to properly model the "agent", its interactions and its physiology. The recognition of this fact has steered research to first gather data to properly inform model parameters. In particular, to study the population level effect of acoustic disturbances, the following must be known (under a wide but feasible parameter range and ecological conditions) about physiological and behavioural changes attributable to sound exposure:

- Environmental effects (such as temperature, ocean dynamics, pollution) on the different stages of the species lifecycle.
- Vulnerability to disturbance to sound according to size and age of individuals, including larvae.
- Specific and reliably measured impacts of sound on the species (e.g., impact on foraging, on hearing, on mating, on swimming, on general fitness, etc.). The tables in sections 4.2 and 4.3 list important impacts that must be better known and quantified, in conditions ranging from over-exposure to minimal exposure.
- Interactions through trophic layers (death, growth, spawning, and predation rates; catch rates from fishing).
- Existing stock levels, competition among species.

From the preceding sections, it should be clear that many of the above data requirements are very challenging and difficult to achieve, hence PCoD models such as those mentioned remain academic experiments. Most data acquired to date, in much of the research highlighted in this study, is of little or no use for a number of reasons, as discussed. However, the quality in experiment design and the number of researchers tackling these complex issues are steadily growing, so the current tendency, as reliable data becomes available from research, is to gradually develop operational models that can provide reliable estimates of population level effects of anthropogenic noise from site investigation and other marine surveys on fish and shellfish. It is possible that, in the future, these techniques will be used to assess the effect not only of surveys but of the entire ORE development, helping to best inform appropriate assessments (AA) at the early stages of the consenting process, or to determine the impacts of operations which could lead to radical changes in the way multi-use of space is currently looked at.

Meanwhile, until these models become generally available, the effects of site investigation surveys on fisheries must be assessed otherwise. As previously mentioned, the results from similar research are sometimes contradictory, and other times lacking detail. For many species, research is simply non-existent. However, if an effort is made to “filter” the results and retain any common threads or baselines, some useful information can be extracted, even though they may require further confirmation. The following is a list of insights thus provided:

- The principal cause of concern (for fish and shellfish) from site investigation surveys is the use of sound by marine survey instruments.

- Of these, the most impactful instruments are those used in high resolution geophysical (also known as seismic) surveys, such as single airguns and airgun arrays.

- Nearly all site investigation surveys do not plan to use airguns or airgun arrays and, thus, should be more benign to fish and shellfish than seismic surveys (which have been the major driving force for the vast majority of impacts found in the scientific literature).

- Boomer and sparker systems, also used in HRG surveys, operate at lower power levels, as do most other research instruments, and should be less impactful than airguns.

- It is generally accepted that most research instruments used in site investigation surveys do not cause significant impacts to fish and shellfish.

- Instant mortality of both fish and shellfish due to site investigation surveys is very unlikely. During this desktop study, no evidence of significant fish or invertebrate mortality due to these surveys was found.

- Impacts on fish and shellfish behaviour during the survey is likely and mostly temporary. This impact is most commonly behavioural, although some species may suffer physical impact (depending on several factors such as SPL, cumulative SEL, distance to the source, sensitivity to acoustic noise, sensitivity to particle motion, capacity to find shelter, capacity to leave the area). Whether the temporary behavioural or reduced physical impact have population level consequences is currently not known, although the coexistence of fisheries with other forms of marine exploitation in many areas suggest that any population level consequence on fisheries could be minimal.

- The impact from site investigation surveys should be most noticeable in the close vicinity of the survey, up to a few thousand meters of the survey vessel, and particularly around the vessel's vertical. As the survey vessel covers the survey site and since the survey area is usually much larger than this, the impact will be distributed throughout the area; however, depending on the survey plan and the area extent, the effects on fish and shellfish will vary in time across the survey area.

- It cannot be generalised that the impact eventually observed on an individual in a sub-area of the survey site will be found in individuals of the same species in other sub-areas, or in individuals of similar species.

- Positive and negative effects on fisheries (catches) during surveys have been reported; however, in practical terms, fishing activity is restricted in surveys areas altogether, and this could be more impactful on catches than the impacts of the survey itself.

- Research has found that it is difficult to accurately determine impact of the survey in the post-survey phase, since there are other environmental and physiological factors that may be significant as well. Several studies have found that catches tend to recover in time (from days to several weeks), but this is inconclusive.

6. CONCLUSIONS

The ocean is the habitat of all marine life. For millions of years, fish and shellfish, as well as all forms of marine life, have had enough time to evolve and to become ideally adapted to an environment in which light plays a small role. Sound and motion are the main components of a constantly changing landscape whose dimensions and complex interactions we have only recently begun to fully realise. An increasing number of research papers highlight the fact that it is not only the "soundscape" that matters when analysing impacts of human activity on this environment, but that the entire "landscape" (understood as the perceived result of a multi-sensorial input set, of which sound is just another element) must be considered, such is the sensitivity and diversity of sensory information that marine life utilises. For example, if, on one hand, bivalves and gastropods seem completely unaffected by sound and react to other stimuli (e.g., variations in temperature and salinity, or to particle motion), some fish are so specialised in sensing their environment that they can detect particle displacements in the order of 0.1 nm (accelerations in the order of 10^{-5} ms^{-2}) and have a hearing system 10^{5} times more sensitive than humans.

The fact that the large majority of existing studies address the impacts of seismic surveys using airguns (seen by many experts as the most impactful form of current marine research and, thus, acting as a sort of an "impact upper bound" in what concerns this study) has allowed the research community to produce useful advice in terms of measures to mitigate eventual impacts on marine animals. This is especially true for marine mammals, which have been the subject of protection regulations and mitigation or monitoring guidance. Examples of this are the Joint Nature Conservation Committee's (JNCC) "Guidelines for minimising the risk of injury to marine mammals from geophysical surveys" (JNCC, 2017). The Irish equivalent of the JNCC guidelines is currently (at the time of writing this report) being updated by the National Parks and Wildlife Service. The guidelines include mitigation measures aimed essentially at marine mammals, among which soft starts, pre-survey airgun testing, visual searches for mammals, special procedures for survey line changes or survey breaks, etc. Although high-resolution seismic surveys using airguns or airguns arrays are not expected in site investigation surveys, these mitigation measures would, in general, also benefit fish and shellfish to some extent (for instance, soft starts, during which the power at the acoustic source is gradually increased by pre-determined steps, can help fish in avoiding the area thus reducing impact). Other additional measures could also be considered for site investigation surveys, such as due regard to fish spawning grounds and seasons.

It is interesting to note that the JNCC considers that geophysical surveys not using airguns and limited to using MBES in shallow waters do not require any special mitigation measure, since the sound levels and frequencies utilised by these systems in shallow waters are outside the hearing range of cetaceans and likely to attenuate more rapidly than the lower frequency sounds of HRG survey equipment.

The European Union's Marine Strategy Framework Directive (MSFD), with its Descriptor 11 on anthropogenic sound and the definition of Good Environmental Status which, for acoustic underwater noise, includes two monitoring indicators, one for impulsive sound sources in the range 10 Hz to 10 kHz – indicator 11.1.1, and the other for continuous noise in the 1/3 octave bands of frequencies 63 Hz and 125 Hz – indicator 11.2.1 (MSFD, 2013) is more broad in application and is not only focused on marine mammals. It specifically mentions possible impact from pile driving on harbour porpoises (evasive behaviour), from airgun surveys on many cetaceans (evasive behaviour) and on fish (sundry disturbance) and from sonar on beaked whales (strong aversive reaction). Although the guidance to monitor anthropogenic marine sound resulting from the MSFD is not intended to provide mitigation measures from human activity at sea, it does present a good reference on how to measure and monitor sound in the ocean.

As discussed further above, any site investigation survey will cause some sort of impact (see section 5.3), depending on factors such as the species present at the time and location of the survey, the techniques used in the survey, the duration of the survey, the timing of the survey in relation to ecological cycles, etc. Although critical impact to fish and shellfish populations from site investigation geophysical and geotechnical surveys is highly unlikely, the exact nature and extent of minor impacts (such as avoidance or habituation) is currently not well understood. It could be argued that the relative absence of long term impact studies in research, and the continued fishing operations in areas subject to high marine engineering and construction activities for decades, such as the North and Baltic Seas, are indicative that long term effects on fisheries are not significant enough to profoundly impact fisheries. Therefore, even lesser impacts could be expected from the much less impactful, temporary activities typical of site investigation surveys (in fact, MBES and SBP have been used worldwide for the last half-century or so, with no reports of significant, if at all, harm to marine life).

It is thus important to stress at this point that, in the research review carried out in this study, no evidence was found of direct impacts attributable to site investigation surveys; the discussion and results in the preceding sections stem from what can be inferred from the more impactful seismic surveys. However, as a matter of caution, it seems good practice to try and minimise the number of geotechnical and geophysical surveys in the same or adjacent areas, or to space them in time, to allow fish and shellfish populations to recover in between, and to share existing data to the largest extent possible.

There are many aspects of sensory information processing by fish and shellfish that are still unknown and, consequently, so are the extent and nature of impacts that human activities cause on fish and shellfish. In spite of the research already carried out, there is a need to do much more research to cover important gaps in our knowledge, such as:

- Investigation of sensitivity of fish to infrasound.
- Investigation of the impact of acoustic sources with lower source levels and higher frequency ranges.
- Investigation of the effects of particle motion.
- Investigation of the relationship between particle motion and sound pressure levels in complex environments, such as the coastal ocean or the bottom boundary layer.
- Investigation of the diverse physiological rates of fish and shellfish, needed to inform critical parameters required for population modelling. In parallel, investigation of species interactions for the same purpose.
- Investigation of the long term effect of sound on fish populations.

In fact, further laboratory-based research to address the above gaps would help provide a better understanding of the potential impact of geophysical and geotechnical site investigation surveys on fish and shellfish populations. Obviously, to gain a comprehensive understanding of these impacts, research that focuses on the specific types of equipment used in these surveys is needed to gain insight into how they might affect the behaviour or physiology of relevant commercially fished species. There are commercially fished species, such as the common whelk, for which there have been no relevant studies; this research will likely be driven by scientific curiosity rather than by industry needs.

The offshore renewables industry could perhaps address shorter term goals. Further studies, such as using scientific echosounders mounted on AUVs to record echograms on fish shoals and schools during surveys, and visual monitoring of less mobile species or collection of biological samples, could provide useful information to assess fish (and possibly shellfish) behaviour during geophysical and geotechnical surveys. These studies could be preceded by pre- and post-survey monitoring. As Ireland moves into a plan led approach to ORE developments, with centralised site investigation surveys favoured over developer led surveys, this could be the ideal timing to add these much needed components to the proposed survey work.

BIBLIOGRAPHY

André, M., Solé, M., Lenoir, M., Durfort, M., Quero, C., Mas, A., Lombarte, A., van der Schaar, M., López-Bejar, M., Morell, M., Zaugg, S., & Houégnigan, L. (2011). Low frequency sounds induce acoustic trauma in cephalopods. Frontiers in Ecology and the Environment, 9(9), 489–493. https://doi.org/10.1890/100124

Andriguetto-Filho, J. M., Ostrensky, A., Pie, M. R., Silva, U. A., & Boeger, W. A. (2005). Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. Continental Shelf Research, 25(14), 1720–1727. https://doi.org/10.1016/j.csr.2005.05.003

Bolle, L. J., de Jong, C. A. F., Bierman, S. M., van Beek, P. J. G., van Keeken, O. A., Wessels, P. W., van Damme, C. J. G., Winter, H. V., de Haan, D., & Dekeling, R. P. A. (2012). Common sole larvae survive high levels of pile-driving sound in controlled exposure experiments. PLoS ONE, 7(3). https://doi.org/10.1371/journal.pone.0033052

Caiger, P., Montgomery, J., & Radford, C. (2012). Chronic low-intensity noise exposure affects the hearing thresholds of juvenile snapper. Marine Ecology Progress Series, 466, 225–232. https://doi.org/10.3354/meps09933

Casper, B. M., Smith, M. E., Halvorsen, M. B., Sun, H., Carlson, T. J., & Popper, A. N. (2013). Effects of exposure to pile driving sounds on fish inner ear tissues. Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology, 166(2), 352–360. https://doi.org/10.1016/j.cbpa.2013.07.008

Celi, M., Filiciotto, F., Vazzana, M., Arizza, V., Maccarrone, V., Ceraulo, M., Mazzola, S., & Buscaino, G. (2015). Shipping noise affecting immune responses of european spiny lobster (Palinurus elephas). Canadian Journal of Zoology, 93(2), 113–121. https://doi.org/10.1139/cjz-2014-0219

Codarin, A., Wysocki, L. E., Ladich, F., & Picciulin, M. (2009). Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). Marine Pollution Bulletin, 58(12), 1880–1887. https://doi.org/10.1016/j.marpolbul.2009.07.011

Davidsen, 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., Sjursen, A. D., Rønning, L., Netland, T. C., & Hawkins, 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). https://doi.org/10.1093/

conphys/coz020.

Day, R. D., McCauley, R. D., Fitzgibbon, Q. P., Hartmann, K., & 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 of the United States of America, 114(40), E8537–E8546. https://doi.org/10.1073/pnas.1700564114.

de Soto, N. A., Delorme, N., Atkins, J., Howard, S., Williams, J., & Johnson, M. (2013). Anthropogenic noise causes body malformations and delays development in marine larvae. Scientific Reports, 3(1), 2831. https://doi.org/10.1038/srep02831.

Dooling, R. J., Leek, M. R., & Popper, A. N. (2015). Effects of noise on fishes: What we can learn from humans and birds. In Integrative Zoology (Vol. 10, Issue 1, pp. 29–37). Wiley-Blackwell. https://doi.org/10.1111/1749-4877.12094.

Edmonds, N. J., Firmin, C. J., Goldsmith, D., Faulkner, R. C., & Wood, D. T. (2016). A review of crustacean sensitivity to high amplitude underwater noise: Data needs for effective risk assessment in relation to UK commercial species. In Marine Pollution Bulletin (Vol. 108, Issues 1–2, pp. 5–11). Elsevier Ltd. https://doi.org/10.1016/j.marpolbul.2016.05.006.

EngÅs, A., & LØkkeborg, S. (2002). Effects of seismic shooting and vessel-generated noise on fish behaviour and catch rates. Bioacoustics, 12(2–3), 313–316. https://doi.org/10.1080/09524622.2002.9753733.

Farina, A. (2018). Environmental Impact of Underwater Noise: sound pressure and particle velocity.

Fewtrell, J. L., & McCauley, R. D. (2012). Impact of air gun noise on the behaviour of marine fish and squid. Marine Pollution Bulletin, 64(5), 984–993. https://doi.org/10.1016/j.marpolbul.2012.02.009.

Filiciotto, F., Vazzana, M., Celi, M., Maccarrone, V., Ceraulo, M., Buffa, G., Stefano, V. Di, Mazzola, S., & Buscaino, G. (2014). Behavioural and biochemical stress responses of Palinurus elephas after exposure to boat noise pollution in tank. Marine Pollution Bulletin, 84(1–2), 104–114. https://doi.org/10.1016/j.marpolbul.2014.05.029.

Gausland, I. (2003). Report for Norwegian Oil Industry Association (OLF): Seismic Surveys Impact on Fish and Fisheries.

Handegard, N. O., Michalsen, K., & Tjøstheim, D. (2003). Avoidance behaviour in cod (Gadus morhua) to a bottom-trawling vessel.

Aquatic Living Resources, 16(3), 265–270. https://doi.org/10.1016/S0990-7440(03)00020-2.

Hawkins, A. D., Pembroke, A. E., & Popper, A. N. (2015). Information gaps in understanding the effects of noise on fishes and invertebrates. Reviews in Fish Biology and Fisheries, 25(1), 39–64. https://doi.org/10.1007/s11160-014-9369-3

Hirst, A. G., & Rodhouse, P. G. (2000). Impacts of geophysical seismic surveying on fishing success. In Reviews in Fish Biology and Fisheries (Vol. 10).

Hubert, J., Campbell, J. A., & 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. https://doi.org/10.1016/j.marpolbul.2020.111680.

Jansen, E., Prior, M., & Brouns, E. (2019). On the conversion between sound pressure and particle motion. Proceedings of Meetings on Acoustics, 37(1). https://doi.org/10.1121/2.0001280.

JNCC. (2017). JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys.

Kaifu, K., Akamatsu, T., & Segawa, S. (2008). Underwater sound detection by cephalopod statocyst. Fisheries Science, 74(4), 781–786. https://doi.org/10.1111/j.1444-2906.2008.01589.x.

Kane, A. S., Song, J., Halvorsen, M. B., Miller, D. L., Salierno, J. D., Wysocki, L. E., Zeddies, D., & Popper, A. N. (2010). Exposure of fish to high-intensity sonar does not induce acute pathology. Journal of Fish Biology, 76(7), 1825–1840. https://doi.org/10.1111/j.1095-8649.2010.02626.x.

Løkkeborg, S., Ona, E., Vold, A., & Salthaug, A. (2012). Sounds from seismic air guns: Gear-and speciesspecific effects on catch rates and fish distribution. Canadian Journal of Fisheries and Aquatic Sciences, 69(8), 1278–1291. https://doi.org/10.1139/F2012-059.

McCauley, R. D., Fewtrell, J., & Popper, A. N. (2003). High intensity anthropogenic sound damages fish ears. The Journal of the Acoustical Society of America, 113(1), 638–642. https://doi.org/10.1121/1.1527962.

Mcqueen, K., Meager, J. J., Nyqvist, D., Skjæraasen, J. E., Olsen, E. M., Karlsen, Ø., Kvadsheim, P. H., Handegard, N. O., Forland, T. N., & 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). https://doi.

org/10.1093/icesjms/fsac203.

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., Vaughan, B., & Parsons, M. J. G. (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). https://doi.org/10.1073/pnas.2100869118.

Methratta, E. T. (2020). Monitoring fisheries resources at offshore wind farms: BACI vs. BAG designs. ICES Journal of Marine Science, 77(3), 890–900. https://doi.org/10.1093/icesjms/fsaa026.

Mickle, M. F., Pieniazek, R. H., & Higgs, D. M. (2020). Field assessment of behavioural responses of southern stingrays (Hypanus americanus) to acoustic stimuli. Royal Society Open Science, 7(1). https://doi.org/10.1098/rsos.191544.

Morris, C. J., Cote, D., Martin, B., & Kehler, D. (2018). Effects of 2D seismic on the snow crab fishery. Fisheries Research, 197, 67–77. https://doi.org/10.1016/j.fishres.2017.09.012.

MSFD - Monitoring Guidance for Underwater Noise in European Seas - Monitoring Guidance Specifications. 2nd Report of the Technical Subgroup on Underwater Noise (TSG Noise). November, 2013.

Mueller-Blenkle, C., Jones, E., Reid, D., Lüdemann, K., Kafemann, R., & Elepfandt, A. (2008). Reactions of cod gadus morhua to low- frequency sound resembling offshore wind turbine noise emissions. Bioacoustics, 17(1–3), 207–209. https://doi.org/10.1080/09524622.2008.9753819.

Myrberg, A. A., Gordon, C. R., & Klimley, A. P. (1978). Rapid withdrawal from a sound source by open-ocean sharks. http://acousticalsociety.org/content/terms.

Myrberg, A. A., Ha, S. J., Walewski, S., & Banbury, J. C. (n.d.). Effectiveness of acounstic signals in attracting epipelagic sharks to an underwater sound source 1.

Nedelec, S. L., Campbell, J., Radford, A. N., Simpson, S. D., & Merchant, N. D. (2016). Particle motion: the missing link in underwater acoustic ecology. Methods in Ecology and Evolution, 7(7), 836–842. https://doi.org/10.1111/2041-210X.12544.

Olivier, F., Gigot, M., Mathias, D., Jezequel, Y., Meziane, T., L'Her, C., Chauvaud, L., & Bonnel, J. (2023). Assessing the impacts of anthropogenic sounds on early stages of benthic invertebrates: The

"Larvosonic system." Limnology and Oceanography: Methods, 21(2), 53–68. https://doi.org/10.1002/lom3.10527.

Parry, G. D., & Gason, A. (2006). The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. Fisheries Research, 79(3), 272–284. https://doi.org/10.1016/j.fishres.2006.03.023.

Payne, J. F., Andrews, C. A., Fancey, L. L., Cook, A. L., & Christian, J. R. (n.d.). Pilot Study on the Effects of Seismic Air Gun Noise on Lobster (Homarus americanus) 1+1 Fisheries P~ches and Oceans et Oceans. In Canadian Technical Report of Fisheries and Aquatic Sciences.

Pecquerie, L., Petitgas, P., & Kooijman, S. A. L. M. (2009). Modeling fish growth and reproduction in the context of the Dynamic Energy Budget theory to predict environmental impact on anchovy spawning duration. Journal of Sea Research, 62(2–3), 93–105. https://doi.org/10.1016/j.seares.2009.06.002.

Peng, C., Zhao, X., & Liu, G. (2015). Noise in the sea and its impacts on marine organisms. In International Journal of Environmental Research and Public Health (Vol. 12, Issue 10, pp. 12304–12323). MDPI. https://doi.org/10.3390/ijerph121012304.

Pine, M. K., Nikolich, K., Martin, B., Morris, C., & Juanes, F. (2020). Assessing auditory masking for management of underwater anthropogenic noise. The Journal of the Acoustical Society of America, 147(5), 3408–3417. https://doi.org/10.1121/10.0001218.

Popper, A. N., & Fay, R. R. (2011). Rethinking sound detection by fishes. Hearing Research, 273(1–2), 25–36. https://doi.org/10.1016/j.heares.2009.12.023.

Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., Coombs, S., Ellison, W. T., Gentry, R. L., Halvorsen, M. B., Løkkeborg, S., Rogers, P. H., Southall, B. L., Zeddies, D. G., & Tavolga, W. N. (2014). *Sound Exposure Guidelines* (pp. 33–51). https://doi.org/10.1007/978-3-319-06659-2_7

Popper, A. N., & Hawkins, A. D. (2019). An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. In Journal of Fish Biology (Vol. 94, Issue 5, pp. 692–713). Blackwell Publishing Ltd. https://doi.org/10.1111/jfb.13948.

Radford, A. N., Lèbre, L., Lecaillon, G., Nedelec, S. L., & Simpson, S. D. (2016). Repeated exposure reduces the response to impulsive noise in European seabass. Global Change Biology, 22(10), 3349–3360. https://doi.org/10.1111/gcb.13352.

Roberts, L., Cheesman, S., Breithaupt, T., & Elliott, M. (2015). Sensitivity of the mussel Mytilus edulis to substrate-borne vibration in relation to anthropogenically generated noise. Marine Ecology Progress Series, 538, 185–195. https://doi.org/10.3354/meps11468.

Rossington, K., Benson, T., Lepper, P., & Jones, D. (2013). Eco-hydro-acoustic modelling and its use as an EIA tool. Marine Pollution Bulletin, 75(1–2), 235–243. https://doi.org/10.1016/j.marpolbul.2013.07.024.

Sand, O. (2023). A journey through the field of fish hearing. The Journal of the Acoustical Society of America, 153(5), 2677–2689. https://doi.org/10.1121/10.0017833.

Sierra-Flores, R., Atack, T., Migaud, H., & Davie, A. (2015). Stress response to anthropogenic noise in Atlantic cod Gadus morhua L. Aquacultural Engineering, 67, 67–76. https://doi.org/10.1016/j.aquaeng.2015.06.003.

Slabbekoorn, H., Dalen, J., Haan, D., Winter, H. V., Radford, C., Ainslie, M. A., Heaney, K. D., Kooten, T., Thomas, L., & Harwood, J. (2019). Population level consequences of seismic surveys on fishes: An interdisciplinary challenge. Fish and Fisheries, 20(4), 653–685. https://doi.org/10.1111/faf.12367.

Solan, M., Hauton, C., Godbold, J. A., Wood, C. L., Leighton, T. G., & White, P. (2016). Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties. Scientific Reports, 6. https://doi.org/10.1038/srep20540.

Stimpert, Alison. K., Madrigal, B. C., Wakefield, W. W., & Yoklavich, M. M. (2019). Acoustic influence of underwater mobile survey vehicles on the soundscape of Pacific rockfish habitat. The Journal of the Acoustical Society of America, 146(1), EL45–EL51. https://doi.org/10.1121/1.5109914.

Van der Knaap, I., Reubens, J., Thomas, L., Ainslie, M. A., Winter, H. V., Hubert, J., Martin, B., & Slabbekoorn, H. (2021). Effects of a seismic survey on movement of free-ranging Atlantic cod. Current Biology, 31(7), 1555-1562.e4. https://doi.org/10.1016/j.cub.2021.01.050.

Vold, A., Lokkeborg, S., & Tenningen, M. M. (2012). Using Catch Statistics to Investigate the Effects of Seismic Activity on Fish Catch Rates. Advances in Experimental Medicine and Biology, 730, 411–415. http://www.springer.com/series/5584.

Wale, M. A., Simpson, S. D., & Radford, A. N. (2013). Noise negatively affects foraging and antipredator behaviour in shore crabs. Animal Behaviour, 86(1), 111–118. https://doi.org/10.1016/j.anbehav.2013.05.001.

APPENDIX 1

BASICS OF OCEAN ACOUSTICS

This appendix develops some ocean acoustics concepts and quantities, necessary to better understand technical characteristics of survey equipment, the research and the discussion on sound impacts on marine life.

Sound in the ocean is acoustic energy propagating as compressive (longitudinal) waves, that is, waves in which the particles that compose the medium oscillate about a rest position in the direction of wave propagation, with origin at some sound source. With sound, this means that, while the wave propagates, there are alternating regions of compression and decompression along the propagation path and particles in the medium move back and forth.

The usual parameters to describe waves apply to sound: amplitude, wavelength, direction of propagation, frequency and phase. Wavelength and frequency are related to the speed of wave propagation, which in turn depends on properties of the medium. In the ocean, the velocity of sound depends mostly on temperature, salinity and pressure (i.e., the major variables controlling density and, hence, what is known as "acoustic impedance" – the measure of the ease with which a sound wave propagates through a particular medium). The average speed of sound in seawater is about 1,500 m/s.

As sound waves propagate in a medium, such as seawater, or from one medium to another (e.g., from seawater into sediments), the acoustic energy released at the source suffers several physical processes, usually grouped in three main groups: i) absorption, in which some energy is lost to the environment due to friction or viscosity; ii) reflection, in which some energy is reflected at the interface of two regions with different acoustic properties, and iii) refraction, in which energy is transmitted from one medium to another. Reflection and refraction can both make the direction of propagation of the incoming energy (wave) change; depending on the wavelength and the nature of the interface between propagating media, reflection and refraction can occur in multiple directions (which is known as "scatter"), some of which back to the source (backscatter). Scatter can also take place while the sound wave propagates in a medium that contains very small particles in suspension, as it is common in seawater.

Due to the above [4], the acoustic energy released at the source will decrease with distance to the source and its direction will vary [5]. Since the velocity of sound waves ultimately depends on the density of the medium, slight variations in density will cause reflection and refraction to occur, to some greater or lesser extent (this is, of course, most noticeable in the interface between air and sea, and at the seabed, where significant variations of density are present in the respective propagating media). Therefore, an inverse problem can be stated and solved to determine properties of the propagating media, if measurements of acoustic energy at several points along the propagation path(s) are made (at least two, one source and one receiver, but multiple sources and receivers can be used – with increased complexity). This is, in simple terms, the principle behind all scientific acoustic instruments used in marine surveys.

MEASUREMENT OF SOUND

A sound wave has an **amplitude** equal to the maximum distance a particle is displaced from rest. The more energy in the sound wave, the larger the amplitude. Amplitude can also be defined for the variations in pressure – the pressure amplitude being the maximum pressure relative to that at rest. The **wavelength** of a wave is the distance between two successive compressions ("crests") or the distance the wave travels in one cycle of vibration (in meter). The **frequency** of a sound wave is the rate of oscillation or vibration of the wave particles (in Hertz, or cycles per second). The **phase** (in radians) can be described as how far in the cycle a wave is, at a given location and at a reference time; phase is important in the way that waves interact with each other. These four parameters completely describe a sound wave. In addition, for sound waves propagating in a geographical space, **the direction of propagation** can also be defined in relation to the vertical and to the geographical north (i.e., elevation/depression and azimuth).

SOUND SPEED

It is the velocity of wave propagation. In single-frequency (monochromatic) waves, speed is the ratio of wavelength and frequency. The average sound speed in the ocean is 1,500 m/s.

[4] Other factors, such as loss due to geometrical spreading of the energy released, also come into play. The so-called Sonar Equation usually considers a "Transmission Loss" factor that encompasses absorption, scattering and geometrical spreading in a single loss term.

[5] The propagation of sound is a complex phenomenon, treated here simplistically to allow for easier understanding. The effects of diffraction and multipath propagation are beyond the scope of this appendix, as well as boundary effects. All can lead either to decreased or increased sound amplitude locally.

SOUND PRESSURE

Pressure is force per unit area, with unit pascal (Pa). Sound pressure is the force exerted by a sound wave in a unit area of propagating medium. Since the waveform varies in time, represented by sinusoidal oscillations for simplicity, it is necessary to define what pressure is being used; several options exist, the most used being peak or peak-to-peak (the difference between the minimum and maximum pressure from static pressure – in the absence of a sound wave) for impulsive sound, and root mean square (RMS) of the pressure variation over a full cycle for continuous sound.

The instantaneous sound pressure (*p* (t)) can be related to the density of the medium (*p*), the instantaneous velocity of the oscillating particles (v(t)), and the speed of sound in the medium (c).

$$p(t) = \rho p c v(t) \quad (Pa)$$

SOUND INTENSITY

The intensity of a wave is power per unit area in the direction of propagation, in watt per meter squared. The intensity of a sound wave is related to its pressure amplitude squared by the following relationship:

$$I = (\Delta p)^2 / 2\rho c \quad (W/m^2)$$

The quantity "**ρc**" is called the acoustic impedance of the medium.

SOUND INTENSITY LEVEL

Sound intensities exist in a very large range of values. For instance, the human ear can detect sound intensities from 1×10^{-12} W/m^2 to 1×10^{2} W/m^2 (the latter already causing damage to the ear). Therefore, it is more useful to define a logarithmic scale for sound intensity, the sound intensity level:

$$SIL = 10 \log_{10}(I / I_0) \text{ in decibel (dB)}$$

The reference intensity I_0 is 1×10^{-12} W/m^2 (in the air). Thus, the SIL is the intensity of a given sound relative to a reference level, in this case, the threshold for human hearing in the air.

SOUND PRESSURE LEVEL

The same rationale applies to sound pressure, and a Sound Pressure Level can be defined which is much more useful than sound pressure itself:

$$SPL = 20_{\log 10}(p / P_0) \quad (dB)$$

where P_0 = $1x10^{-6}$ Pa (or 1 μPa) is the reference pressure in the ocean, and $20x10^{-6}$ Pa (or 20 μPa) in air. This reference pressure is taken as the root mean squared (RMS) pressure measured at a standard distance of 1m from the source.

Note that it is important to explicitly state the reference pressure (or intensity) when indicating SPL or SIL, although it has nearly become a standard to use the above references (that is, ref. 1 μPa @ 1 m in the ocean, and, ref. 20 μPa @ 1 m in air).

There are also significant differences between the perception of sound in water and in air. For instance, the SPL for the same sound pressure in air and in the ocean differ by 26 dB:

$$SPL_{water} - SPL_{air} = 20 \log_{10}(P_{0\,air}/P_{0\,water}) = 20 \log_{10} 20 = 26\ dB$$

$$SPL_{water} = SPL_{air} + 26\ dB$$

Further, due to the difference in acoustic impedance between air and water (the acoustic impedance in water being about 3600 times greater than in air), there is an additional ~36 dB difference when considering the SIL in air and water for the same sound pressure:

$$10 \log_{10} 3600 = 35.5\ dB$$

Therefore:

$$SIL_{water} = SIL_{air} + 62\ dB$$

The above relationship may be useful when trying to compare, in practical terms, the sound perceived by a diver (or a marine animal) if exposed to the same sound out of the water. For example, the sound produced by a humpback whale, whose SPL can reach about 180 dB (ref. 1 μPa @ 1 m), would be as loud as a pneumatic chipper at a distance of 2 m or a loud rock concert (about 120 dB), if the whale produced the same sound in air. Viewed from another perspective, this relationship indicates that **sounds of similar intensities (in air and in water) are technically described by much higher SPL in water than in air.** To a less informed person, this can give the false impression that sounds are much louder in water than they are in air.

Most acoustic equipment used in ocean surveying is commonly specified in terms of SPL or of power emitted at the source. When SPL is used, often there's no indication of whether it refers to peak, or peak-to-peak, or RMS pressure. The relations between peak, peak to peak and RMS sound pressure levels can be easily found, since (assuming a sinusoidal wave pattern for the sound pulse) $P_{RMS} = (1/\sqrt{2})\,P_{PEAK}$ and $P_{RMS} = (1/2\sqrt{2})\,P_{P\text{-}P}$, which give:

$$SPL_{RMS} = 20\log_{10}((1/\sqrt{2})\,P_{PEAK}/P_0) = 20\,(\log_{10}(P_{PEAK}/P_0) + \log_{10}(1/\sqrt{2})) = SPL_{PEAK} - 3dB$$

$$SPL_{RMS} = SPL_{P\text{-}P} - 9dB$$

These relations hold for sinusoidal waves of constant amplitude throughout the duration of the signal. Impulsive sound can vary significantly from this, as the amplitude of the sound pulse decreases over time (i.e., the RMS value of these signals will be smaller than indicated above).

SOUND EXPOSURE LEVEL

When considering impacts from exposure to sound, it is useful to introduce another quantity that takes into account the amount of time a receiver is subject to a specific sound. As mentioned in section 4.1, sound sources can be continuous or intermittent, with the latter further divided in impulsive and non-impulsive [6]. Impulsive sources are usually taken as those in which a sound is emitted for no longer than a few milliseconds.

Continuous sounds, even sounds with relatively low SPL, can produce effects in marine life after some time of exposure (e.g., low frequency, continuous shipping noise may cause habituation, or change of behaviour in animals). On the other hand, impulsive sound of very high intensity but very short duration can cause significant damage to life if the receiver is close enough to the source (e.g., the sound produced by an underwater explosion will produce a very short but very high SPL that will likely kill sound-sensitive animals in the explosion's near field). The quantity Sound Exposure (E) integrates the sound pressure squared over the period of time of the sound duration:

$$E = \int_{(t-\Delta t)}^{(t+\Delta t)} p(t)^2\,dt, \quad (Pa^2.s)$$

If a reference sound exposure is quantified using a reference pressure (P_0) and a standard sound duration T_0, then the quantity Sound Exposure Level (SEL) is defined as

$$SEL = 10\log_{10}(E/E_0) \text{ in dB, where } E_0 = T_0 \cdot P_0^2$$

[6] These categories are generally followed in regulations on environmental status and monitoring. For instance, the Marine Strategy Framework Directive (MSFD) considers different monitoring requirements for impulsive and for continuous sound sources in the ocean, in terms of maximum desired levels and frequency bins to monitor.

The reference sound exposure can vary among applications, but it has become accepted to use 1 $\mu Pa^2.s$ in the ocean (that is, the reference sound pressure and a standard sound duration of 1 s).

SEL can be used to compare the effect of sounds of different intensities. It also allows to infer or estimate changes in impacts of sound with changes in the source. For instance, a survey vessel generates less noise if she moves slower (SPL decreases) but SEL may actually increase as the ship will take more time to cover the same distance.

Under certain assumptions, a relation can also be found between SPL and SEL. Note that the expressions for both are similar and use the same references. If the sound is emitted in a single strike pulse (SEL_{SS}), then the following relation can be easily obtained:

$$SEL_{SS} = SPL + 10 \log_{10}(T) ,$$

with "T" de duration of the pulse in seconds. In the case of a series of identical pulses of equal duration and equal sound pressure levels, then a cumulative SEL (SEL_{CUM}) can be estimated as

$$SEL_{CUM} = SEL_{SS} + 10 \log_{10}(N),$$

in which N is the number of pulses. In this case, the interval between pulses should also be considered when analysing impacts, in addition to frequency and other factors, because hearing cavities and sensors can recover in between pulses.

PARTICLE MOTION

A quantity that has recently received attention from the research community in terms of impact on hearing physiology of fish is ***particle motion*** or ***particle velocity***. As mentioned above, the propagation of a compressive sound wave means the particles that compose the medium oscillate in the direction of wave propagation about a rest position. The particles' displacement is a function of amplitude (power or pressure variation) and frequency of the wave:

$$\xi(t) = p(t)/(2\pi f \rho c) \sqrt{(1+(\lambda/2\pi r)^2)}$$

This expression is valid away from boundaries, and it reduces to $\xi (t) = p(t) / (2\pi f \rho c)$ in the far field of the source, where the distance to the source (r) is large enough to consider a plane wave. For reference, a 10 kHz wave with a SPL of 100 dB re 1 μPa will generate particle displacements of about 1.04×10^{-12} m, or roughly 1 pm, in the far field of the source, with peak velocities of about 10 nm/s and peak accelerations in the order of 600 $\mu m/s^2$.

Once the displacement is known, velocity and acceleration can be computed. Hearing systems can be sensitive to any of these processes, but mostly to acceleration.

It is possible to define log-scaled dB levels for particle displacement, velocity and acceleration, using the reference values of 1 pm, 1 nm/s and 1 μm/s², respectively. For instance, the particle velocity level (PVL) is given by:

$$PVL = 20 \log_{10}(v/v_0), \quad \text{in dB ref 1 nm/s}$$

In studies of impacts of sound on marine life, particle velocities should ideally be measured with adequate equipment since the approximations used to compute PVL from SPL (based on the relation $I = p.v$) result in an underestimation of particle velocity levels (Jansen et al., 2019, Farina, 2018), especially for low frequencies (below 1 kHz).

SOUND ATTENUATION IN THE OCEAN

As mentioned further above, attenuation of sound intensity as it propagates in seawater depends on several factors, among which interaction with boundaries, absorption in the medium, scattering, and geometrical spreading from the source. Modern sound propagation models use physical principles for each of these terms to compute the changes in intensity and in direction as a sound wave propagates.

For quick estimates in practical applications in which the distance to the source is not too large (that is, in which it can be considered that absorption is much smaller that geometrical spreading), simple models of geometrical spreading can provide a first approximation to the variation of sound levels with distance to the source. It is common to use either spherical or cylindrical spreading (the former for point sources away from boundaries, the latter more appropriate for point sources in shallow water).

In spherical spreading, and using the assumption that the absorption in the medium is negligible, the power radiated in all directions from the source remains more or less the same, that is,

$$P = 4\pi r^2 I = P_0 = 4\pi r_0^2 I_0 \rightarrow I = I_0 (r_0^2 / r^2)$$

In other words, the intensity decreases with the inverse of the squared distance to the source. The attenuation level in sound intensity, or Transmission Loss (TL), is then given by (using a reference r_o of 1 m):

$$TL_{sph} = -10\log_{10}(I/I_0) = 20\log_{10}(r) \quad \text{in dB,}$$

$$\text{(r in meter from the source)}$$

For cylindrical spreading, the variation in sound intensity is proportional to the inverse (horizontal) distance to the source, and it is easy to show that:

$$TL_{cyl} = 10\log_{10}(r) \quad \text{in dB, (r in meter from the source)}$$

SOME COMPARATIVE VALUES OF SPL

The following table shows indicative SPL for common sounds in the ocean, to help give context to figures found in technical documents and specifications; care should be exercised when comparing sound levels, as not always reference or standard procedures are followed to measure sound, or overly simplifying assumptions are sometimes made to achieve a value.

Table 0.1 lists SPL, not SEL, for sounds with origin in natural geophysical processes, sound made by marine mammals and sounds with anthropogenic sources; Note that SBP and MBES are included in the table for comparison purposes only, since they operate at higher frequencies than the other sounds listed (hence the remark “off-band”).

Source	Max. SPL (ref. 1µ Pa @ 1m	Remarks
Undersea Earthquake	272	Magnitude 4.0 on Richter scale (energy integrated over 50 Hz bandwidth)
Seafloor Volcano Eruption	255+	Massive steam explosions
Airgun Array (Seismic)	255	Compressed air discharged into piston assembly
Lightning Strike on Water Surface	250	Random events during storms at sea
Sub-bottom profiler	< 247 dB (off-band)	Maximum power from ins-truments deployed at the surface
Multibeam echo-sounder	245 dB (off-band)	Power typically used in deep-sea mapping
Boomer, sparker and other seismic exploration devices	212-230	Includes sparker, gas slee-ve, exploder, water gun and boomer seismic profiling methods
Container Ship	198	Length 274 meters; Speed 23 knots
Supertanker	190	Length 340 meters; Speed 20 knots
Blue Whale	190 (avg. 145-172)	Vocalizations: Low frequen-cy moans
Fin Whale	188 (avg. 155-186)	Vocalizations: Pulses, moans
Offshore Drill Rig	185	Oil/gas exploration drilling
Offshore Dredge	185	Motor Vessel AQUARIUS
Humpback Whale	180 (avg. 175-180)	Fluke and flipper slaps
Bowhead Whale	180 (avg. 152-180)	Vocalizations: Songs
Right Whale	175 (avg. 172-175)	Vocalizations: Pulsive signal
Gray Whale	175 (avg. 175)	Vocalizations: moans
Fishing Vessel	150 dB	12m LOA @ 7 knots
Open Ocean Ambient Noise	74-100 (71-97 dB in deep sound chan-nel)	Estimate for offshore sea state 3-5; expected to be higher (>= 120 dB) when vessels present

Table 0.1 – SPL for common sounds in the ocean: white color label - natural sources of marine ambient noise; yellow color label - sounds produced by marine an-imals; orange color label - anthro-pogenic noise)

APPENDIX 2 – DETAILS OF RECENT FORESHORE LICENSE APPLICATIONS FOR SITE INVESTIGATION SURVEYS

Owner	Date	Status	Site	When	Where	Objectives / Techniques
EirGrid	22/05/2023	Applied	FS007661 - EirGrid - Offshore Renewable Grid Infrastructure - Waterford and Wexford	Q1 2024	Up to 12nm off Waterford and Wexford	EirGrid Public Limited Company propose to undertake geophysical and geotechnical site investigation works, environmental surveys; including marine, for the purpose of informing the location and development of offshore electricity transmission infrastructure to facilitate renewable energy.
EirGrid	23/05/2023	Applied	FS007660 EirGrid Site Investigations to inform Offshore Renewable Grid Infrastructure, Co Cork		Up to 12nm off Cork	Geophysical and geotechnical site investigation works, environmental surveys; including marine, for the purpose of informing the location and development of offshore electricity transmission infrastructure to facilitate renewable energy.
SSE Renewables	17/03/2023	Applied	FS007608 SSE Renewables Tarbert Offshore Wind Farm	Any time from 2023	Off the coast of counties Clare, Limerick and Kerry	This site survey and investigation works to inform the possible development by considering the substrate stability and understanding the best location for siting an OWF. These works would determine the suitability for cable routeing and the positioning of turbines and other electrical infrastructure associated with the possible development of an Offshore Wind Farm.
Sure Partners Ltd	27/04/2023	Applied	FS007555 - Arklow Bank Wind Park off coast of County Wicklow	Any time from 2023	A site area named "Arklow Bank Wind Park", situated off the coast of Wicklow.	The submitted licence application is in respect of site surveys at the Foreshore Licence Area as part of an ongoing survey schedule for Arklow Bank Wind Park to maintain up to date baseline information for the site.
Amazon MCS Ireland Ltd	06/04/2023	Applied	FS007618 Amazon MC Ireland Ltd. Geophysical Survey and Site Investigations	ASAP for 1 to 6 months	Landfall at Castlefreke Warren / Castlefreke Island, Rathbarry, Co. Cork	Geophysical survey and site investigations for a proposed subsea fibre optic cable having a landfall in County Cork to evaluate options for the route traversing Glandore Bay and landfall at Castlefreke
Péarla Offshore Wind Limited	24/10/2022	Applied	FS007621 Péarla Offshore Wind Limited - Site Investigations For Export Cable Corridor For A Proposed Offshore Wind Project		Off County Waterford.	Péarla Offshore Wind Limited are applying for a Foreshore Licence to undertake surveys and investigations to inform the route of installation of an export cable corridor to connect a proposed fixed foundation offshore wind project (the "Péarla Project") in the Celtic Sea (approximately 44km off the coast of Waterford at the nearest point) to the grid

Owner	Date	Status	Site	When	Where	Objectives / Techniques
MaresConnect Ltd	03/03/2023	Consultation	FS007635 MaresConnect Electricity Interconnector Site Investigation	Any time, up to 5 months	Investigative landfall zones include: Investigative landfall zones include: Ardgillan - Barnageeragh Cove Balcarrick - Eagans Field Loughshiny - Rockabill View Robswalls - Malahide Rush	Foreshore license application for marine investigative survey works for the MaresConnect Ltd (MCL) Interconnector.
Latitude 52 Offshore Wind Farm Limited	22/12/2021	Applied	FS007232 - DP Energy - Latitude 52 Offshore Windfarm Ltd. Site Investigations off coast of counties Wicklow and Wexford		Off the coast of counties Wicklow and Wexford	Latitude 52 Offshore Wind Farm Ltd. is applying for a licence to undertake a full suite of site investigations at a site in the west Irish Sea off the coast of County Wicklow and County Wexford. This includes hydrographical and geophysical survey activities (MBES, SSS, SBP, Magnetometer), geotechnical survey activities (boreholes, vibrocores and cone penetration tests) and ecological survey activities (incl. benthic and intertidal sampling, CPODs, Soundtraps) as well as potential deployment of metocean devices (Floating LiDAR, ADCPs and Wave Buoys).
ESB Wind Development Limited	09/12/2021	Consultation	FS007135 - ESB Wind Development Ltd. Site Investigations at Loch Garman Offshore Wind off coast of county Wexford	From Q3 2022, for up to 2 years	A site area named "Loch Garman Offshore Wind", situated off the coast of Wexford.	ESB Wind Development Limited have applied for a Licence to carry out site investigations relating to a possible wind farm on a site named "Loch Garman Offshore Wind", situated off the coast of county Wexford. This foreshore application relates to the Site Investigation works only. These activities are required to inform: the overall project feasibility; the conditions at site and along the cable route; the various assessments required to progress the project; and the development of the project.
Western Star Wind Limited	27/12/2020	Applied	FS007149 Western Star Wind Limited Site Investigations for proposed Offshore Wind Farm, off County Clare	From Spring 2023 up to 5 years	Off County Clare	This foreshore licence application relates to proposed Site Investigations. The proposed project, known as 'Western Star', is proposed to consist of a floating offshore wind site with up to 1.35 GW capacity. Western Star Wind Ltd. currently intends to undertake marine surveys at the proposed development zone and surrounding area to accommodate cable routing analysis for the floating wind project. The reason for the site investigations is to inform the location and design of the proposed development. In this regard the proposed surveys comprise of geophysical, ecological, geotechnical and metocean surveys.
Floating Cork Offshore Wind Limited	22/09/2022	Applied	FS007471 Floating Cork Offshore Wind Limited Site Investigations for proposed Offshore Wind Farm, off County Cork	Any time, for 3 to 6 weeks	Off County Cork	Floating Cork Offshore Wind Limited is seeking to undertake benthic ecology surveys within an offshore export cable corridor area. The surveys are conducted on the shoreline and in the marine area and are routine in establishing the baseline benthic ecology conditions for areas for a number of purposes including conservation, environmental status and in this particular case to support the Environmental Impact Assessment Report for the proposed Floating Cork Offshore Wind Farm

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Malin Head Offshore Wind Limited	22/09/2022	Applied	FS007467 Malin Head Offshore Wind Limited Site Investigations for proposed Offshore Wind Farm, off County Donegal	Mar-Apr or Sep-Oct 2023	Off County Donegal	Malin Head Offshore Wind Limited is seeking to undertake benthic ecology surveys within an offshore export cable corridor area. The surveys are conducted on the shoreline and in the marine area and are routine in establishing the baseline benthic ecology conditions for areas for a number of purposes including conservation, environmental status and in this particular case to support the Environmental Impact Assessment Report for the proposed Malin Head Offshore Wind Farm
RWE Renewables Ireland East Celtic Limited	10/03/2021	Applied	FS007318 RWE Renewables Ireland East Celtic Ltd., Site Investigations for proposed East Celtic Offshore Wind Park, off Counties Wexford and Waterford	Any time from 2023, for nearly one year (2 years for Metocean)	Off Counties Waterford and Wexford	RWE Renewables Ireland East Celtic Limited wishes to investigate the feasibility of developing an offshore wind farm and is applying for a licence to undertake site investigation activities on a site called East Celtic Offshore Wind Park (ECOWP) in the east Celtic Sea, situated in the Celtic Sea off the coasts of County Wexford and County Waterford. The ECOWP site is divided into the FL Application Area of 389.73km2 and the Future Application Area outside the 12 nm limit of 163.27km2. The FL Application Area at its closest point lies 11.23 km from the Saltee Islands and 9.08 km from mainland Wexford. RWE Renewables is seeking to undertake a variety of marine surveys at the Foreshore Licence Application Area in order to inform the specific location, design and layout of the proposed offshore wind farm.
Blackwater OWL Windfarm Limited	09/05/2022	Applied	FS007445 Blackwater Offshore Wind - Marine Surveys off the coast of Wexford		Off County Wexford	Blackwater OWL Windfarm Limited is seeking to undertake a variety of marine surveys at the proposed site in order to inform the specific location, design and layout of the proposed offshore wind farm and export cable route to shore. The surveys will include geophysical, geotechnical, environmental and metocean campaigns and are detailed in this foreshore licence application form and supporting documents. Specifically, the objective of the proposed Foreshore Licence Application works is to determine detailed site conditions including seafloor geology, metocean conditions and environmental characteristics. The survey results will also provide information to inform the planning and design of a wind farm, including wind, waves, seabed characteristics and marine life
Malin Array Limited	01/02/2021	Applied	FS007395 Malin Array Limited – Site Investigations for proposed offshore wind farm, off County Donegal	early 2023 for 5 years	Off County Donegal	This Foreshore licence application relates to proposed Site Investigation. Malin Array Limited is seeking to undertake a variety of marine surveys at the proposed site in order to form the specific location, design and layout of the proposed offshore wind farm and export cable route to shore. The surveys will include geophysical, geotechnical, environmental, metocean campaigns and are detailed in this foreshore licence application form and supporting documents
Arranmore Wind Limited	14/07/2022	Applied	FS007245 Arranmore Wind Limited Site Investigations for proposed Offshore Wind Farm, off Counties Donegal, Leitrim and Sligo	early 2023 for 5 years	Off Counties Donegal, Leitrim, Sligo	Arranmore Wind Limited is seeking to undertake a variety of marine surveys at the proposed site in order to inform the specific location, design and layout of the proposed Arranmore Wind Park at a site off the coasts of Donegal, Leitrim and Sligo and the export cable route to shore. The surveys will include geophysical, geotechnical, environmental and metocean campaigns and are detailed in the foreshore licence application form

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Illen Array Ltd	24/05/2022	Applied	FS007244 Illen Array Ltd. Site Investigations for proposed Offshore Wind Farm, off Counties Kerry and Clare	early 2023 for 5 years	Off Counties Kerry and Clare	Illen Array Ltd. is seeking to undertake a variety of marine surveys at the proposed site in order to inform the specific location, design and layout of the proposed Ilen Array Offshore Wind Farm in the Atlantic Ocean off the coasts of county Kerry and Clare and export cable route to shore. The surveys will include geophysical, geotechnical, environmental and metocean campaigns and are detailed in the foreshore licence application form
Farraige Renewables Ltd	25/11/2019	Applied	FS007074 Farraige Renewables Ltd. – Site Investigations for proposed offshore wind farm, off County Wexford	Over the coming years	Wexford	This Foreshore licence application relates to proposed site investigations on the proposed development site. This application is intended to cover all site investigation activities required to progress an offshore wind farm concept to detailed design stage
Saoirse Wave Energy Limited	02/07/2021	Applied	FS007372 Saoirse Wave Energy Limited Site Investigations for proposed Wave Energy Conversion (WEC) project, off County Clare	Spring 2023, up to 5 years	Off County Clare	Saoirse Wave Energy Limited, a group company of Simply Blue Holdings Limited (SBE), is currently investigating the feasibility of a wave energy conversion (WEC) project located off the coast of County Clare. The applicant intends to undertake marine surveys at the proposed wave energy development zone and surrounding area to accommodate cable routing analysis. An additional site area is included to allow for flexibility in the proposed technology should further studies identify a more viable wave energy concept
Mac Lir Offshore Wind Limited	22/09/2022	Applied	FS007472 Mac Lir Offshore Wind Limited Site Investigations for proposed Offshore Wind Farm, off Counties Wexford, Wicklow and Dublin	early 2023 for 5 years	Off Counties Wicklow, Wexford and Dublin	Mac Lir Offshore Wind Limited is seeking to undertake benthic ecology surveys within a potential offshore export cable corridor area. The proposed surveys will be conducted on the shoreline and in the marine area and are routine in establishing the baseline benthic ecology conditions for areas for a number of purposes including conservation, environmental status and in this particular case to support the Environmental Impact Assessment Report for the proposed Mac Lir Offshore Wind Farm
Celtic Offshore Renewable Energy Limited	22/04/2022	Applied	FS007488 Celtic Offshore Renewable Energy Site Investigations for proposed Offshore Wind Farm, off Counties Wexford and Waterford	2023, over 5 years	Off Counties Wexford and Waterford	Foreshore Licence Application for site investigations for the overall Celtic Offshore Renewable Energy Project, which relates to a mixed offshore floating and fixed wind farm located off the southeast coast of Ireland, predominantly off the coast of county Wexford, and to a lesser extent Waterford. Activities undertaken will include surveys considered necessary to properly assess the viability of the project across a spectrum of geotechnical, environmental and metocean factors

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Leinster Offshore Wind Limited	02/10/2020	Applied	FS007162 Leinster Offshore Wind Limited Site Investigations off County Dublin	Q2 2023 up to 2 years	Off County Dublin	The application for a foreshore licence for Leinster Offshore Wind Limited is to survey a new area for a proposed fixed foundation offshore wind project (the "Leinster Project") in the Irish Sea approximately 14km off the east coast of Ireland. The Leinster Project would be for a development of an offshore wind farm with a likely capacity of around 500MW. The Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the proposed site. The proposed foreshore licence area covers the wind farm array area only. A separate Foreshore Licence will be applied for to cover transmission requirements (e.g., export cables and landfall) in 2022
Wicklow Sea Wind Ltd, a subsidiary company of Inis Offshore Wind Ltd	26/08/2022	Consultation	FS007588 Site Investigations by Wicklow Sea Wind Ltd for Cable Route off County Wicklow	Q3 2023 up to 3 months	Off County Wicklow	Inis Offshore Wind Limited with the support of Warwick Energy has identified projects that could support the Irish Government's Climate Action Plan and 5 GW capacity targeted for 2030. The foreshore license application for Wicklow Sea Wind Limited is to survey an area suitable for the installation of an export cable corridor to connect a proposed fixed foundation offshore wind project in the Celtic Sea (approximately 8km off the east coast of Wicklow) to the grid. The Foreshore License application is to undertake the surveys and investigations to inform the route of the export cable corridor. The cable AoS covers the transmission assets area only. A separate Foreshore License was submitted (Wicklow Foreshore License Application: Reference: FS007163) in 2021 to cover the offshore wind generation assets
ESB Wind Development Limited, a wholly owned subsidiary of ESB	22/12/2021	Consultation	FS007137 ESB Wind Development Ltd. Moneypoint Offshore Wind Farm - Site Investigations off Clare and Kerry Coasts	2023 4 months up to 36 months (metocean)	Off coast of counties Clare & Kerry	The 'Moneypoint Offshore Wind' project is comprised of two projects, namely Moneypoint Offshore One Wind and Moneypoint Offshore Two which are both proposed as floating offshore wind projects. Moneypoint Offshore One is located to the west of County Clare and County Kerry at approximately 15.5km from shore. The main export cable corridor area of search for the Moneypoint Offshore Wind projects is located within the 12 nautical mile (nm) limit with part of the wind turbine generator (WTG) array area of search for Moneypoint Offshore One also within this 12nm limit
Voyage Offshore Array Limited	14/02/2022	Applied	FS007436 Voyage Offshore Array Limited Site Investigations for proposed Offshore Wind Farm, off Counties Waterford and Wexford	2023 for 5 years	Off Counties Waterford and Wexford	The Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the proposed site of Voyage Offshore Array Limited's proposed Voyage Offshore Array offshore wind project. The overall Voyage Offshore Array Project relates to an offshore floating wind farm located which will be located off the west coast of Ireland, predominantly off the coast of Waterford and south county Wexford. Proposed surveys include Geophysical, Geotechnical, and Environmental. A phased approach to development will be taken

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Rian Offshore Array Limited	27/01/2022	Applied	FS007435 Rian Offshore Array Limited Site Investigations for proposed Offshore Wind Farm, off Counties Kerry and Clare	2023 for 5 years	Off Counties Kerry and Clare	The Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the proposed site of Rian Offshore Array Limited's proposed Rian Offshore Array offshore wind project. The overall Rian Offshore Array Project relates to an offshore floating wind farm located which will be located off the west coast of Ireland, predominantly off the coast of north Kerry and county Clare. Proposed surveys include Geophysical, Geotechnical, and Environmental. A phased approach to development will be taken
Tulca Offshore Array Limited	14/02/2022	Applied	FS007431 Tulca Offshore Array Limited Site Investigations for proposed Offshore Wind Farm, off County Cork	2023 for 5 years	Off County Cork	The Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the proposed site of Tulca Offshore Array Limited's proposed Tulca Offshore Array offshore wind project. Proposed surveys include Geophysical, Geotechnical, and Metocean. A phased approach to development will be taken
Greystones OWL Windfarm Limited	29/06/2022	Applied	FS007367 Greystones (OWL) Windfarm Ltd proposing to develop offshore windfarm off Dublin/ Wicklow	2023 for 5 years	Off Counties Wicklow and Dublin	Greystones OWL Windfarm Limited is proposing to develop an offshore wind farm at a site off the Wicklow/Dublin coast. Greystones OWL Windfarm Limited is seeking to undertake a variety of marine surveys at the proposed site to inform the specific location, design and layout of the proposed offshore wind farm and export cable route to shore.
It should be noted the Foreshore Acts 1933 to 2014 allows for the granting of Investigatory Foreshore Licences inside the 12NM limit and, as such, this application relates only to the area within that jurisdiction						
Valentia Island Energy Ltd	20/06/2022	Applied	FS007365 Valentia Island Energy Ltd Site Investigations for proposed Offshore Floating Wind Farm, off County Kerry	2023 for 5 years	Off County Kerry	The overall Valentia Island Energy Ltd Project relates to an offshore floating wind farm at a proposed location off the coast of Valentia Island, county Kerry off the southwest coast of Ireland. This Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the project. Proposed surveys include Geophysical, Geotechnical, Environmental and Metocean

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Kinsale Offshore Wind Limited	26/08/2022	Consulta-tion	FS007575 Kinsale Offshore Wind Limited Site Investigations for Export Cable Corridor for proposed Offshore Wind Farm, off County Cork	Q3 2023 up to 3 months	Off County Cork	The Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the proposed site of Kinsale Offshore Wind Limited's proposed fixed foundation offshore wind project in the Celtic Sea off Co. Cork. Proposed surveys include Geophysical, Archaeological, Subtidal, Marine benthic ecology flora and fauna and Geotechnical
Réalt na Mara Offshore Wind Farm Limited	24/03/2021	Applied	FS007330 - Réalt na Mara Offshore Wind Farm Ltd, site investigations off the coasts of Wicklow and Dublin	2023 for 5 years	Off Counties Wicklow and Dublin	This Foreshore Licence Application is for site investigation works to determine the suitability for cable routeing, and positioning of turbines and other electrical infrastructure associated with the development of an OWF. The results of these surveys will also provide baseline data for Environmental Impact Assessment (EIA) and a subsequent Environmental Impact Assessment Report (EIAR) should the development be taken forward to the planning/consenting stage
Kerry Offshore Wind Limited	16/03/2022	Applied	FS007363 Kerry Offshore Wind Limited Site Investigations for proposed Offshore Wind Farm, off Counties Kerry and Clare	Q2 2023 for 3 months (up to 3 years Metocean)	Off Counties Kerry and Clare	The Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the proposed site of Kerry Offshore Wind Limited's proposed fixed foundation offshore wind project. Proposed surveys include Geophysical, Archaeological, Subtidal, Seabird and marine mammal boat based and aerial, Geotechnical and Deployment of wind and current resource measurement devices
Bore Array Ltd, a subsidiary project company of Statkraft	08/04/2022	Applied	FS007464 - Bore Array Ltd, Site Investigation for Bore Array Offshore Wind Farm, off Co. Wexford	2023, any time, for 3-4 months, up to 12 months (metocean)	Off County Wexford	Bore Array Ltd, a subsidiary project company of Statkraft, is investigating the feasibility of developing the Bore Array Offshore Wind Farm (OWF), off the coast of Co. Wexford. The intention is that the final development would be linked by an export cable (or cables) to shore. This Foreshore Licence Application is for site investigation works to determine the suitability for cable routeing, and positioning of turbines and other electrical infrastructure associated with the development of an OWF. The results of these surveys will also provide baseline data for Environmental Impact Assessment (EIA) and a subsequent Environmental Impact Assessment Report (EIAR) should the development be taken forward to the planning/consenting stage
Munster Sea Wind Limited	16/03/2022	Applied	FS007366 Munster Sea Wind Limited Site Investigations for proposed Offshore Wind Farm, off County Clare	Q3 2023 up to 3 months (36 months for metocean)	Off County Clare	The Foreshore Licence application is to undertake the surveys and site investigations to inform development and project design for the proposed site of Munster Sea Wind Limited's proposed fixed foundation offshore wind project. Proposed surveys include Geophysical, Archaeological, Subtidal, Seabird and marine mammal boat based and aerial, Geotechnical and Deployment of wind and current resource measurement devices

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Celtic Horizon Offshore Wind Farm Limited	02/06/2021	Applied	FS007384 Celtic Horizon Offshore Wind Farm Limited Site Investigations for proposed Offshore Wind Farm, off Counties Wexford and Waterford	Spring 2023, up to 3 years	Off Counties Wexford and Waterford	Foreshore Licence Application for site investigations. The purpose is investigating the feasibility of developing an offshore bottom-fixed wind farm in the south coast of Ireland, off counties Wexford and Waterford. The surveys in the investigations will include a combination of invasive and non-invasive survey activities, consisting geophysical, geotechnical, archaeological, ecological, metocean and benthic surveys
Haven Offshore Array Limited	14/02/2022	Applied	FS007434 Haven Offshore Array Limited Site Investigations for proposed Offshore Wind Farm, off County Donegal	2023, up to 5 years	Off County Donegal	Foreshore Licence Application for site investigations for the overall Haven Offshore Array Project, which relates to an offshore floating and static wind farm located off the north coast off county Donegal. Activities undertaken will include surveys considered necessary to properly assess the viability of the project across a spectrum of geophysical, technical, environmental, social, and economic factors
Aniar Offshore Array Limited	14/02/2022	Applied	FS007189 Aniar Offshore Array Limited Site Investigations for proposed Offshore Wind Farm, off Counties Sligo, Leitrim and Donegal	2023, up to 5 years	Off Counties Sligo, Leitrim and Donegal	Foreshore Licence Application for site investigations for the overall Aniar Offshore Array Project, which relates to an offshore floating and static wind farm located off the west coast of Ireland, in Donegal Bay predominantly off the coast of counties Sligo, Leitrim and Donegal. Activities undertaken will include surveys considered necessary to properly assess the viability of the project across a spectrum of geophysical, technical, environmental, social, and economic factors
Atlantic Offshore Renewable Energy 2	22/12/2021	Applied	FS007495 Atlantic Offshore Renewable Energy 2 – Site Investigations for proposed offshore wind farm, off County Galway		Off County Galway	The Atlantic Offshore Renewable Energy 2 Project relates to an offshore static and/or floating wind farm located off the west coast of Ireland, off the coast of County Galway. This licence, if granted, will allow Atlantic Offshore Renewable Energy 2 to carry out necessary site investigation surveys which will enable the project to confirm the most suitable site and design for offshore wind energy production off the coast Galway.
Atlantic Offshore Renewable Energy 1	22/12/2021	Applied	FS007494 Atlantic Offshore Renewable Energy 1 – Site Investigations for proposed offshore floating wind farm, off County Mayo		Off County Mayo	The Atlantic Offshore Renewable Energy 1 Project relates to an offshore floating wind farm located off the west coast of Ireland, predominantly off the coast of Mayo. This licence, if granted, will allow Atlantic Offshore Renewable Energy 1 to carry out necessary site investigation surveys which will enable the project to confirm the most suitable site and design for offshore wind energy production off the coast of Mayo. The objective of the site investigation work is to understand site conditions including benthic characteristics, bathymetry, underlying geology, existing tidal conditions, and environmental characteristics.

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Aigean Renewables Limited	25/11/2019	Consultation	FS007063 Aigean Renewables Ltd., Site Investigations for the proposed Moneypoint Offshore Wind Array, off County Kerry	2023 up to 5 years	Off County Kerry	Aigean Renewables Ltd have applied for a Foreshore Licence for the purpose of undertaking Site Investigations to inform the engineering and design of the potential Moneypoint Offshore Wind Array, off County Kerry. The objectives of the proposed works are to: acquire comprehensive understanding of metocean conditions; minimize uncertainty in ground conditions to inform detailed design for future developments; determine detailed environmental data of the site; enable preparation of an EIAR. In order to meet the above objectives, various Site Investigation works and monitoring device deployments are required, for which a Foreshore Licence is required.
Lir Offshore Array Limited	07/12/2021	Applied	FS007392 Lir Offshore Array Ltd., Site Investigations for the proposed Lir Offshore Array, off Counties Louth, Meath and Dublin	2023 up to 5 years	off the coasts of Balbriggan and Drogheda, and counties Louth, Meath and Dublin	The Foreshore Licence application is to undertake surveys and Site Investigations (SI) to inform development and project design for the proposed site. The surveys will be geophysical, geotechnical, environmental and metocean. It should be noted the Foreshore Acts 1933 to 2014 allows for the granting of Investigatory Foreshore Licences inside the 12 Nautical Mile limit and, as such, this application relates only to the area within that jurisdiction
Codling Wind Park Limited	19/05/2022	Determi-nation	FS007546 Codling Wind Park Ltd. Site Investigations for proposed Offshore Wind Farm, off Counties Wicklow and Dublin	Q2 2023 up to 7 years	Off County Wicklow and County Dublin	The main aims and objectives of the proposed activities are to: - Provide up to date detailed bathymetric mapping of the seabed; - Provide further information on the soil stability and morphology of the seabed; - Provide detailed information on ground conditions and geology; - Obtain up to date wind resource and metocean data for the site; and - To generate environmental and ecological data to inform the EIA and AA for the Codling Wind Park project.
Wicklow Sea Wind Limited, a subsidiary company of Inis Offshore Wind Ltd	10/01/2020	Consultation	FS007163 Wicklow Sea Wind Ltd., Site Investigations for the proposed Wicklow Project offshore wind farm, off County Wicklow	2023 up to 3 years	Off County Wicklow	The Foreshore Licence application is to undertake surveys and site investigations to inform development and project design for the proposed site. The surveys will gather further information on: seabed and sub-seabed conditions; geotechnical data on the stability of soils, sediments, clays and gravels to allow the characterisation of the sub-seabed strata to inform design; wind and metocean (wave, current, tide and water levels) information; provide the project team with baseline information on the environmental conditions at the site, including marine ecology, bird, mammals and benthos; provide the project team with information on the archaeological conditions at the site. In order to meet the above objectives various Site Investigation (SI) works and monitoring device deployments are required, for which a Foreshore Licence is required. The proposed foreshore licence area covers the wind farm array area only.

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Kinsale Offshore Wind Limited	10/01/2022	Consulta-tion	FS007354 Kinsale Offshore Wind Ltd, Site Investigations for the proposed Kinsale Project off-shore wind farm, off County Cork	2023 up to 3 years	Off County Cork	The FL application is to undertake surveys and site investigations to inform development and project design for the proposed site on: seabed and sub-seabed conditions; geotechnical data on the stabi-lity of soils, sediments, clays and gravels to allow the characterisa-tion of the sub-seabed strata to inform design; wind and metocean (wave, current, tide and water levels) information; provide the pro-ject team with baseline information on the environmental conditions at the site, including marine ecology, bird, mammals and benthos; provide the project team with information on the archaeological conditions at the site. In order to meet the above objectives various Site Investigation (SI) works and monitoring device deployments are required, for which a Foreshore Licence is required. The proposed foreshore licence area covers the wind farm array area only.
Banba Wind Limi-ted	23/12/2021	Consulta-tion	FS007283 Banba Wind Ltd., Site Inves-tigations for propo-sed Offshore Wind Farm, off Counties Wicklow and Dublin	2022 (2023) up to 5 years	Off County Wicklow and County Dublin	Foreshore licence application for site investigation activities to undertake a variety of marine surveys at the Foreshore Licence Application Area in order to inform the specific location, design and layout of the proposed offshore wind farm and export cable route to shore. The surveys will include geophysical, geotechnical, envi-ronmental, metocean campaigns. The objectives of the site investi-gations and marine surveys is to determine detailed site conditions including seafloor geology, metocean conditions and environmental characteristics. The survey results will inform the planning and de-sign of a proposed wind farm.
Sunrise Wind Li-mited	23/12/2021	Consulta-tion	FS007151 Sunrise Wind Ltd., Site In-vestigations for the proposed Sunrise Offshore Wind Farm, off Counties Dublin and Wicklow	2022 (2023) up to 5 years	Off County Dublin and County Wicklow	Foreshore licence application for site investigation activities to undertake a variety of marine surveys at the proposed site in order to inform the specific location, design and layout of the proposed offshore wind farm and export cable route to shore. The surveys will include geophysical, geotechnical, environmental and metocean campaigns. The site investigation surveys in the proposed Foreshore Licence Application Area will support the development of the pro-posed Sunrise Offshore Wind Farm.
Fuinneamh Sceir-de Teoranta	16/05/2022	Consulta-tion	FS007543 Fuinne-amh Sceirde Teo-ranta - Site Inves-tigations for the proposed Sceirde Rocks Offshore Wind Farm (Export Cable Corridor)	2023 for up to 5 years	Off County Galway	Sceirde Rocks Offshore Wind Farm is a fixed bottom offshore wind farm off the West Coast of Ireland and under the Transitional Pro-tocol is recognised as a Relevant or Phase One project. As such, Sceirde Rocks Offshore Wind Farm is a high priority project and it is anticipated that this project will be prioritised through the Fo-reshore License process, the MAC award process and subsequently will be one of the first projects eligible for the first ORESS-1 auction. Sceirde Rocks Offshore Wind Farm will be targeting an accelerated delivery programme for this offshore project to meet government renewable energy targets pre-2030. This application specifically re-lates to a foreshore license for site investigation activities along the project's proposed offshore export cable corridors.

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Clarus Offshore Wind Farm Limited (DP Energy)	19/11/2021	Consultation	FS006886 Clarus Offshore Wind Farm - Site Investigations off Counties Kerry and Clare	Asap for up to 5 years	Off the coast of Clare	Clarus Offshore Wind Farm Ltd. is applying for an Investigative Foreshore Licence to undertake a full suite of site investigations at a Cable Investigation Area associated with the potential Clarus Offshore Wind Farm. The duration of the Investigative Foreshore License sought is requested to extend over a minimum of 5 years. The proposed site investigations have been designed to help assess potential export cable corridors and cable landfall areas associated with the potential Clarus Offshore Wind Farm, under Investigative Foreshore Licence application FS006886. The results of these site investigations will be used to select optimal export cable route(s), cable landfall option(s) and to provide baseline data for environmental appraisal.
ESB Wind Development Limited	20/12/2020	Consultation	FS007138 ESB Celtic Offshore Wind - Site Investigations off Waterford and Cork	2023 up to 3 years	Off the Cork and Waterford coast	The Celtic Offshore Wind project is comprised of two projects, one fixed and one floating. Celtic Offshore Wind is located to the south of county Cork and to the southwest of county Waterford. The fixed project (Celtic One) is approximately 7.5 km from shore. The export cable corridor for the floating project (Celtic 2) is the only aspect of the floating project that lies within the 12nm limit. For the purposes of this application the application area includes Celtic One and the export cable corridor for Celtic 2.
Fuinneamh Sceirde Teoranta	16/02/2022	Consultation	FS007161 Fuinneamh Sceirde Teoranta - Site Investigations for the proposed Sceirde Rocks Offshore Wind Farm	2023 for up to 5 years	Off County Galway	Sceirde Rocks Offshore Wind Farm is a fixed bottom offshore wind farm off the West Coast of Ireland and under the Transitional Protocol is recognised as a Relevant or Phase One project. As such, Sceirde Rocks Offshore Wind Farm is a high priority project and it is anticipated that this project will be prioritised through the Foreshore License process, the MAC award process and subsequently will be one of the first projects eligible for the first ORESS-1 auction. Sceirde Rocks Offshore Wind Farm will be targeting an accelerated delivery programme for this offshore project to meet government renewable energy targets pre-2030. This application specifically relates to a foreshore license for site investigation activities in the wind farm array area only.
Mainstream Renewable Power Ltd	03/06/2021	Consultation	FS007374 Mainstream Renewable Power Ltd - Site Investigations off Co. Wexford	2022 up to 5 years	Off Wexford and Waterford coast	Following a strategic review of opportunities for commercial scale offshore wind in Ireland, Mainstream has identified potential search or investigation areas which are based on available data and minimise potential impacts to a number of key stakeholders. The cable corridors and windfarm investigation areas are search areas (i.e. the Proposed Windfarm Investigation Area and the Proposed Cable Investigation Area) in which surveys will be carried out to determine where infrastructure could be located following technical review, feasibility studies, modelling of the data acquired and stakeholder consultation. The Wexford Foreshore Licence Application Area (referred to as "Wexford" thereafter) covers an area of approximately 731.8 km2 (73170 Ha) and is located approximately off the west coast of County Wexford and County Waterford, Ireland.

Owner	Date	Status	Site	When	Where	Objectives / Techniques
Mainstream Renewable Power Ltd	03/06/2021	Consultation	FS007373 Mainstream Renewable Power Ltd - Site Investigations off Co. Dublin	2022 up to 5 years	Off the coast of Dublin	Foreshore Licence for Site Investigations to inform feasibility assessments and design in relation to the proposed development of an offshore wind farm array to the east of County Dublin.
Mainstream Renewable Power Ltd	03/06/2021	Consultation	FS007375 Mainstream Renewable Power Ltd - Site Investigations off Tralee	2022 up to 5 years	Off the Kerry and Clare coasts	The entire area of Mainstream's interest lies partly within and partly outside the 12 nautical mile (nm) limit. The total area (i.e. both within and outside the 12 nm boundary) is 2,617 km2. The Tralee Foreshore Licence Application Area (including the Proposed Windfarm Investigation Area and the Proposed Cable Investigation Area, see lies partly within and partly outside the 12 nautical mile (nm) limit. It is acknowledged that, at this time, it is only possible to obtain a Foreshore Site Investigation Licence under the Foreshore Act 1933 (as amended) for the area, and associated survey works, within the 12 nm boundary. Site investigations and surveys outside the 12 nm limit will be subject to a separate consenting process.
ESB Wind Development Limited	18/12/2020	Consultation	FS007136 ESB Wind Development Limited Site Investigations off Waterford and Cork Coasts - Helvick Head Offshore Wind	2022 up to 3 years	South of County Waterford and to the southeast of County Cork	Foreshore Licence for Site Investigations to inform the engineering and design of a potential offshore wind farm and associated export cable route at a site named "Helvick Head Offshore Wind".
ESB Wind Development Limited (ESB), a wholly owned subsidiary of ESB	23/11/2020	Consultation	FS007134 ESB Wind Development Limited Site Investigations at Sea Stacks Offshore Wind off Dublin and Wicklow	2022 up to 5 years	A site area named "Sea Stacks Offshore Wind", situated off the Dublin and Wicklow coasts	ESB Wind Development Limited have applied for a Licence to carry out site investigations relating to a possible wind farm on a site named "Sea Stacks Offshore Wind", situated off the coasts of Dublin and Wicklow. This foreshore application relates to the Site Investigation works only. These activities are required to inform: the overall project feasibility; the conditions at site and along the cable route; the various assessments required to progress the project; and the development of the project.
Oriel Windfarm Limited	21/05/2021	Determi-nation	FS007383 Oriel Windfarm Limited, Site Investigations for the proposed offshore Oriel Wind Farm	2022 up to 2 years	Off the coast of County Louth, to the east of Dundalk Bay	Oriel Windfarm Limited (Oriel) is an Irish renewable energy company developing the proposed Oriel offshore wind farm located in the North-West Irish Sea, 22km off the coast of Dundalk, County Louth. The proposed Oriel offshore wind farm will include wind turbines mounted onto a foundation installed into the seabed, an offshore substation and interlinking cabling between the turbines and the substation and an export cable between the substation and the shore. Oriel has applied for a Foreshore Licence to undertake detailed geotechnical and geophysical investigations, ecological surveys and metocean surveys. The purpose of the geotechnical investigation is to investigate the stability of the soil for the design of foundations and the detailed routing of the inter array and export cables. The purpose of the geophysical survey is to characterise the layers of sediment/rock underneath the seafloor and to achieve a detailed seabed morphology and seafloor mapping. Further ecological surveys and measurements of the wind, wave and currents (metocean) will also be undertaken.

Owner	Date	Status	Site	When	Where	Objectives / Techniques
RWE Renewables Ireland Ltd	01/10/2021	Determi-na-tion	FS007188 RWE Renewables Ireland, Site Investigations for the proposed Dublin Array Off-shore Wind Farm	2022 up to 5 years	Off the coast of County Dublin & County Wicklow	Foreshore Licence to undertake geotechnical and geophysical site investigations and ecological, wind, wave and current monitoring to provide further data to refine wind farm design, cable routing, land-fall design and associated installation methodologies for the propo-sed Dublin Array offshore wind farm.
Shelmalere Off-shore Wind Farm	30/11/2020	Consulta-tion	FS007261 Shelmal-ere Offshore Wind Farm - Site Inves-tigations off Coun-ties Wexford and Wicklow	2022, up to 5 years	South-West Irish Sea, off the coasts of Wexford and Wicklow	Foreshore Licence for Site Investigations to inform the engineering and design of a potential offshore wind farm and associated export cable route.
Inis Ealga Mari-ne Energy Park (IEMEP), a subsi-diary company of DP Energy Ireland (DPEI)	30/07/2021	Consulta-tion	FS007404 Inis Ealga Marine Energy Park (IEMEP) site inves-tigations off County Cork	2022, up to 3 years	Off the Coast of County Cork adja-cent to Youghal	This foreshore application relates to the Site Investigation works only. These activities are required to inform: the overall project fea-sibility; the conditions at site and along the cable route; the various assessments required to progress the project; and the development of the project.
Sure Partners Limited	15/04/2021	Determi-na-tion	FS007339 Sure Part-ners Arklow Bank Wind Park Phase 2 Site Investigations	2022, up to 2 years	6-13km off the coast of Wicklow at Ark-low Bank	Sure Partners Limited are applying for a licence to carry out site investigations relating to a possible offshore windfarm off the coast of Wicklow at Arklow Bank. The objectives of the site investigations are to gather sufficient geotechnical information to develop a de-tailed ground model and to gather refined information on the wind resource.
DECC	N/A (no FL application)		DECC Reconnais-sance Geophysical survey	Oct/ Nov 2023	South Coast DMAP	Reconnaissance survey to acquire high resolution geophysical profile data for sub-sea characterisation to inform site selection for potential ORE development. Parallel main lines indicatively 250m separation, crosslines 500m separation. Survey line orientation and length to be adapted during survey pending the geology.

APPENDIX 3 – DETAILS OF LITERATURE REVIEWED TO BUILD IMPACT SUMMARY TABLES

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
1	The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia	Parry, Gregory D.; Gason, Anne	2006	Fisheries Research	Rock Lobster	Air gun arrays (12 to 64 guns)		
2	Assesseing auditory masking for management of underwater anthropogenic noise	Pine, Matthew K.; Nikolich, Katrina; Martin, Bruce; Morris, Corey; Juanes, Francis	2020	Journal of the Acoustical Society of America	Atlantic Cod	Air gun array	22-88 Hz	127 dB re 1 µPa
3	Impacts of geophysical seismic surveying on fishing success	Hirst, Andrew G.; Rodhouse, Paul G.	2000	Reviews in Fish Biology and Fisheries		Air gun arrays (24-32 airguns towed 2-4 vessel lengths behind survey vessel)	20-150 Hz (Can go up to 1,000 Hz)	241-265 dB re 1µPa
4	A large-scale experiment finds no evidence that a seismic survey impacts a demersal fish fauna	Meekan, Mark G.; Speed, Conrad W.; McCauley Robert D.; Fisher, Rebecca; Birt, Matthew J.; Currey-Randall, Leanne M.; Semmens, Jayson M.; Newman Stephen J.; Cure, Katherine; Stowar, Marcus; Vaughan, Brigit; Parsons, Miles J. G.	2021	Proceedings of the National Academy of Sciences	Demersal Fish (*Emperor fish and brownstripe red snapper*)	Airguns Field study	most energy below 100 Hz, almost all energy below 1kHz	231 dB re 1µPa at 1 m RMS, SEL 228 dB re 1µPa2 s, 247dB re 1µPa p-p press.
5	Effects of a seismic survey on movement of free-ranging Atlantic Cod	van der Knaap, Inge; Reubens, Jan; Thomas, Len; Ainslie, Michael A.; Winter Hendrik V.; Hubert, Jeroen; Martin, Bruce; Slabbekoorn, Hans	2021	Current Biology	Atlantic Cod	36 airgun array	40-400Hz	123 dB (SEL_{CUM} over 3.5 day survey period was 186.3 dB)
6	Acoustic influence of underwater mobile survey vehicles on the soundscape of Pacific rockfish habitat	Stimpert, Alison K.; Madrigal, Brijonnay C.; Wakefield, W. Waldo; Yoklavich, Mary M.	2019	Journal of the Acoustical Society of America	Pacific Rockfish	Hydrophones on an AUV detecting survey vessel noise		105 - 112 dB
7	Chronic low-intensity noise exposure affect the hearing thresholds of juvenile snapper	Caiger, Paul E.; Montgomery John C.; Radford, Craig A.	2012	Marine Ecology Progress Series	Snapper (*Pagrus auratus*)	Controlled noise experiment in lab tanks and in the wild.	100-2000Hz	up to 145 dB re 1 µPa

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
8	Exposure of fish to high-intensity sonar does not induce acute pathology	Kane, A. S.; Song, J.; Halvorsen, M. B.; Miller, D. L.; Salierno, J. D.; Wysocki, L. E.; Zeddies, D.; Popper, A. N.	2010	Journal of Fish Biology	Rainbow sunfish Channel catfish Hybrid sunfish	Scanning electron microscopy and on non-auditory tissues using gross and histopathology		193 dB re 1 µPa (rms) or to mid-freq. sounds for 15 s with a received peak SL of 210 dB re 1 µPa (rms).
9	High intensity anthropogenic sound damages fish ears	McCauley, Robert D.; Fewtrell, Jane; Popper, Arthur N.	2003	Journal of the Acoustical Society of America	Pink Snapper (*Pagrus auratus*)	Airguns	20-100Hz (Highest Energy)	100-1000Hz 100 m away 25dB above ambient noise
10	Reactions of cod Gadus morhua to low-frequency sound resembling offshore wind turbine noise emissions	Mueller-Blenkle, Christina; Jones, Emma; Reid, Dave; Ludemann, Karin; Kafemann, Rudolf; Elepfandt, Andreas	2012	Bioacoustics: The International Journal of Animal Sound and its Recording	Cod	Lab based experiment	25, 60, 90, 125, 250 Hz	130-140 dB re 1 µPa
11	Underwater sound detection by cephalopod statocyst	Kaifu, Kenzo; Akamatsu, Tomonari; Segawa, Susumu	2008	Fisheries Science	Webfoot octopus (*Octopus ocellatus*)	Lab based experiment	141Hz	
12	The sense of hearing in the Pacific oyster, Magallana gigas	Charifi, Mohcine; Sow, Mohamedou; Ciret, Pierre; Benomar, Soumaya; Massabuau, Jean-Charles	2017	PLOS One	Pacific Oyster (*Magallana gigas*)	Groups of 16 oysters exposed to quantifiable water-borne sinusoidal sounds in the range of 10 Hz to 20 kHz at various acoustic energies. The expe- riment was con-ducted in running seawater using an experimental flume equipped with suspended loudspeakers.	10 to <1000 Hz Most sensitive to 10 to 200Hz	0.02 ms^{-2} at 122 dB_{rms} re 1 µPa
13	Anthropogenic noise causes body malformations and delays development in marine larvae	de Soto, Natacha Aguilar; Delorme, Natali; Atkins, John; Howard, Sunkita; Williams, James; Johnson, Mark	2013	Nature	New Zealand scallop (*Pecten novaezenlandiae*)	Lab based experiment	24-90Hz	165 dB RMS re 1 µPa

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
14	Low-frequency sounds induce acoustic trauma in cephalopods	André, Michel; Solé, Marta; Lenoir, Marc; Durfort, Mercè; Quero, Carme; Mas, Alex; Lombarte, Antoni; van der Schaar, Mike; López-Bejar, Manel; Morell, Maria; Zaugg, Serge; Houégnigan, Ludwig	2011	Frontiers in Ecology and the Environment	European Squid - *Loligo vulgaris*, Common Cuttlefish - *Sepia officinalis*, Common octopus - *Octopus Vulgaris*, Southern shortfin squid - *Illex coindetti*	Lab based experiment	50-400Hz	157-175 dB re 1 μPa
15	Evaluating the impact of seismic prospecting on artisanal shrimp fisheries	Andriguetto-Filhoa, Jose M.; Ostrensky, Antonio; Pie, Marcio R.; Silva, Ubirata A.; Boeger, Walter A.	2005	Continental Shelf Research	Southern white shrimp - Litopenaeus schmitti Southern brown shrimp - Farfantepenaeus subtilis Atlantic Seabob - *Xyphopenaeus kroyeri*	Airgun Arrays		196 dB re 1 μPa
16	Common Sole Larvae Survive High Levels of Pile-Driving Sound in Controlled Exposure Experiments	Bolle, Loes J.; de Jong, Christ A. F.; Bierman, Stijn M.; van Beek, Pieter J. G.; van Keeken, Olvin A.; Wessels, Peter W.; van Damme, Cindy J. G.; Winter, Hendrik V.; de Haan, Dick; Dekeling, René P. A.	2012	PLOS One	Common Sole (*Solea solea*)	Lab based experiment	50-1000Hz	186-210 dB re 1μPa^{2}s
17	Effects of exposure to pile driving sounds on fish inner ear tissues	Casper, Brandon M.; Smith, Michael E.; Halvorsen, Michele B.; Sun, Huifang; Carlson, Thomas J.; Popper, Arthur N.	2013	Comparative Biochemistry and Physiology	hybrid striped bass (white bass *Morone chrysops* striped bass Morone *saxatilis*) and Mozambique tilapia *Oreochromis mossambicus*			216, 213, or 210 dB re 1 μPa^{2}s cumulative Sound Exposure Level

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
18	Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy)	Codarin, Antonio; Wysocki, Lidia E.; Ladich, Friedrich; Picciulin, Marta	2009	Marine Pollution Bulletin	Damselfish - *Chromis chromis*, Brown meagre - *Sciaena umbra* Red-mouthed goby - *Gobius cruentatus*	Ambient and ship noise were recorded, their sound pressure levels measured and played back in the lab.	100-3000Hz	The average equivalent continuous SPL (LLeq, 1 min) measured over 1 min was 84.5 dB for the lab noise, 99.5 for the playback of ambient noise, and 136.5 dB for the playback of boat noise inside the tub
19	A review of crustacean sensitivity to high amplitude underwatere noise: Data needs for effective risk assessment in relation to UK commercial species	Edmonds, Nathan J.; Firmin, Christopher J.; Goldsmith, Denise; Faulkner, Rebecca C.; Wood, Daniel T.	2016	Marine Pollution Bulletin	Brown crab (*Cancer pagurus*) European lobster (*Homarus gammarus*) Norway lobster (*Nephrops norvegicus*)		20-180 Hz	
20	Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties	Solan, Martin; Hauton, Chris; Godbold, Jasmin A.; Wood, Christina L.; Leighton, Timothy G.; White, Paul	2016	Nature	Nephrops norvegicus	Lab based experiment	100Hz - 2kHz	Continuous sound - 135-140 dB re 1 μPa Impulsive sound - 150 dB re 1 $μPa^2s$
21	EFFECTS OF SEISMIC SHOOTING AND VESSEL GENERATED NOISE ON FISH BEHAVIOUR AND CATCH RATES	Engås, Arill; Løkkeborg, Svein	2012	Bioacoustics: The International Journal of Animal Sound and its Recording				
22	Impact of an air gun noise on the behaviour of marine fish and squid	Fewtrell, J.L.; McCauley, R.D.	2012	Marine Pollution Bulletin	Trevally (*Pseudocaranx dentex*) Pink Snapper (*Pagrus auratus*) Squid (*Sepioteuthis australis*)	air gun		between 120 and 184 dB re 1 lPa^2s (SEL)

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
23	Behavioural and biochemical stress responses of Palinurus elephas after exposure to boat noise pollution in tank	Filiciotto, Francesco; Vazzana, Mirella; Celi, Monica; Maccarrone, Vincenzo; Ceraulo, Maria; Buffa, Gaspare; Di Stefano, Vincenzo; Mazzola, Salvatore; Buscaino, Giuseppa	2014	Marine Pollution Bulletin	Spiny lobster (Palinurus elephas)	Lab based experiment		
24	The Acoustic Response Threshold of the Norway Lobster, Nephrops Norvegicus (L.) in a Free Sound Field	Goodall, Christine; Chapman, Colin; Neil, Douglas Handegard, Nils Olav; Michalsen, Kathrine; Tjøstheim, Dag	1990	Frontiers in Crustacean Neurobiology	*Nephrops norvegicus*	Lab based experiment	20-200Hz	
25	Avoidance behaviour in cod (Gadus morhua) to a bottom-trawling vessel	Løkkeberg, Svein; Ona, Egil; Vold, Aud; Salthaug, Are	2002	Aquatic Living Resources	Cod (*Gadus morhua*)	Split beam echosounder		
26	Sounds from seismic air guns: gear- and speciesspecific effects on catch rates and fish distribution	Svein Løkkeberg Egil Ona Aud Vold Are Salthaug	2012	Canadian Journal of Fisheries and Aquatic Sciences	Redfish (*Sebastes norvegicus*) Greenland halibut (*Reinhardtius hippoglossoides*) Haddock (*Melanogrammus aeglefinus*) Saithe (*Pollachius virens*) Ling (*Molva molva*)	Two Air Gun arrays		
27	Effectiveness of acoustic signals in attracting epipelagic sharks to an underwater sound source	Myrberg Jr, Arthur A.; Ha, S. J.; Walewski, S.; Banbury, J.C.	1972	Bulletin of Marine Science	Silky shark (*Carcharhinus falciformis*) White noise generators		25-1000Hz	
28	Rapid withdrawal from a sound source by open ocean sharks	Myrberg, Jr., Arthur A.; Gordon, Charles R.; Klimley, A. Peter	1978	Journal of the Acoustical Society of America	Silky shark (*Carcharhinus falciformis*)	Playback Experiment		20dB above ambient

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
29	Pilot Study on the Effects of Seismic Air Gun Noise on Lobster (Homarus americanus)	Payne, J.F. Andrews, C.A Fancey, L.L Cook, A.L. Christian, J.R.	2007	Canadian Technical Report of Fisheries and Aquatic Sciences	American lobster (*Homarus americanus*)	Exposures were carried out with a 10 in3 sleeve gun in the laboratory and a 40 in3 sleeve gun in the field.		202 dB to 227 dB
30	Sensitivity of the mussel Mytilus edulisto substrate-borne vibration in relation to anthropogenically generated noise	Roberts, Louise; Cheesman, Samuel; Breithaupt, Thomas; Elliott, Michael	2015	Marine Ecology Progress Series	Mussel (*Mytilus edulis*)	Lab based experiment	5 to 410 Hz	
31	Repeated exposure reduces the response to impulsive noise in European seabass	Radford, Andrew N. ; Lebre, Laurie; Lecaillon, Gilles; Nedelec, Sophie L.; Simpson, Stephend	2016	Global Change Biology	European seabass (*dicentrarchus labrax*)	Lab based experiment	> 10 to < 1500 Hz	130 and 140 dB
32	Spawning Atlantic cod (Gadus morhua L.) exposed to noise from seismic airguns do not aband on their spawning site	McQueen, Kate; Meager, Justin J.; Nyqvist, Daniel; Skjæraasen, Jon Egil; Olsen, Esben Moland; Karlsen, Ørjan; Kvadsheim, Petter H.; Handegard, Nils Olav; Forland, Tonje Nesse; Sivle, Lise Doksæter	2022 ICES Journal of Marine Science	Atlantic cod (Gadus morhua L.)			< 100 Hz	145 dB re 1 μPa²s
33	Effects of 2D seismic on the snow crab fishery	Cote, D.; Morris, C.J.; Regular, P.M.; Piersiak, M.K.	2018	Fisheries REsearch	Snow Crab	BACI Catch Surveys	155 - 163 dB	
34	Effects of sound exposure from a seismic airgun on heart rate, acceleration and depth use in free-swimming Atlantic cod and saithe	Davidsen, Jan G. Dong, Hefeng Linne, Markus Andersson, Mathias H. Piper, Adam Prystay, Tanya S. Hvam, Eivind B. Thorstad, Eva B. Whoriskey, Frederick Cooke, Steven J. Sjursen, Aslak D. Ronning, Lars Netland, Tim C. Hawkins, Anthony D.	2019	Conservation Physiology	Atlantic cod, Saithe	Air Guns		18-60 dB above ambient

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
35	Effects of seismic airgun playback on swimming patterns and behavioural states of Atlantic cod in a net pen	Huber, Jeroen Campbell, James Adam Slabbekoorn, Hans	2020	Marine Pollution Bulletin	Atlantic cod	Air guns	10 - 300 Hz	152, 169 and 174 dB
36	European Seabass respond to noise exposure at night and habituate over repeated trials of sound exposure	Neo, YY Hubert, J Boll, LJ Winter, HV Salbbekoorn, H	2018	Environmental Pollution	European seabass (*dicentrarchus labrax*)	Air guns	200 - 1000Hz	180-192 dB
37	Stress response to anthropogenic noise in Atlantic cod Gadus morhua L.	Sierra-Flores, Rogelio Atack, Tim Migaudm Herve, Davie, Andrew	2015	Aquacultural Engineering	Atlantic Cod		100-1000Hz	
38	Field assessment of behavioural responses of southern stingrays (Hypanus americanus) to acoustic stimuli	Mickel, Megan F. Pieniazek, Rachel H. Higgs, Dennis M.	2020	Royal Society Open Science	Southern Stingray (*Hypanus americanus)*		50-500 Hz	140 dB - 160dB (females and males respectively)
39	Exposure to seismic air gun signals causes physiological harm and alters behavior in the scallop Pecten fumatus	Day, Ryan D. McCauley, Robert Fitzgibbon, Quinn Hartmann, Klaas Semmens, Jayson	2017	Proceedings of the National Academy of Sciences	Scallop (*Pecten fumatus*)	Airguns in fied-based study		Max SPL 191 to 213 dB. Max SEL_{CUM} 189 to 197 dB
40	Shipping noise affecting immune responses of European spiny lobster (Palinurus elephas)	Celi, Monica; Filiciotto, Francesco; Vazzana, Mirella; Arizza, Vincenzo; Maccarrone, Vincenzo; Ceraulo, Maria; Mazzola, Salvatore; Buscaino, Giuseppa	2015	NRC Research Press	European spiny lobster (*Palinurus elephas*)	Lab playback of ship noise	100 Hz - 20 kHz	110 - 120 dB
41	A review of crustacean sensitivity to high amplitude underwater noise: Data needs for effective risk assessment in relation to UK commercial species	Edmonds, Nathan J.; Firmin, Christopher J.; Goldsmith, Denise; Faulkner, Rebecca C.; Wood, Daniel T.;	2016	Marine Pollution Bulletin	Nephrops, Brown Crab, European Lobster	Review Paper		
42	Noise negatively affects foraging and anti-predator behaviour in shore crabs	Wale, Matthew A.; Simpson, Stephen D.; Radford, Andrew N.	2013	Animal Behaviour	Shore Crab (*Carcinus maenas*)	lab-based ship noise playback		148-155 Hz
43	Sesmic surveys impact on fish and fisheries	Gausland, Ingebret	2003	Norwegian Oil Industry Association	Specialist and generalist fish	Airgun arrays	low	232 dB re 1uPa @1m

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
44	Assessing the impacts of anthropogenic sounds on early stages of benthic invertebrates	Olivier, Frédéric; Gigot, Mathilde; Mathias, Delphine; Jezequel, Youenn; Meziane, Tarik ; L'Her, Christophe; Chauvaud, Laurent; Bonnel, Julien	2022	Limnology and Oceanography:Methods (ASLO)	Scallop (*Pecten maximus) larvae*	Lab simulations of pile driving and drilling	10 Hz - 10 kHz	Pile: SPL 100 - 188 dB; SEL 144 - 216 dB Drill: SPL 96 - 175 dB; SEL 143 - 222 dB
45	Hearing sensitivity of the Walleye Pollock	Mann, David A.; Wilson, Christopher D.; Song, Jiakun; Popper, Arthur N.	2009	Transactions of the American Fisheris Society	Walleye Pollock	Lab based experiment	40 - 1600Hz	
46	Categorizing active marine acoustic sources based on their potential to affect marine animals	Ruppel, Carolyn D.; Weber, Thomas C.; Staaterman, Erica R.; Labak, Stanley J.; Hart, Patrick E.	2022	Journal of Marine Science and Engineering	All, but emphasis on marine mammals	MBES, SSS, SBP, boomers, and sparkers acoustic doppler current profilers, split-beam fisheries sonars acoustic releases and locators, navigational transponders	See Tables from Literature Review for more information	
47	An Italian proposal on the monitoring of underwater noise: Relationship between the EU Marine Strategy Framework Directive (MSFD) and marine spatial planning directive (MSP)	Maccarrone, Vincenzo; Filiciotto, Francesco; de Vincenzi, Giovanni; Mazzola, Salvatore; Buscaino, Giuseppa	2015	Ocean & Coastal Management				
48	Population-level consequences of seismic surveys on fishes: An interdisciplinary challenge	Slabbekoorn, Hans; Dalen, John; de Haan, Dick; Winter, Hendrik V.; Radford, Craig; Ainslie, Michael A.; Heaney, Kevin D.; van Kooten, Tobias; Thomas, Len; Harwood, John	2019	Fish and Fisheries				
49	A critical review of the potential impacts of marine seismic surveys on fish and invertebrates	Caroll, A.G.; Przeslawski, R.; Duncan, A.; Gunning, M.; Bruce, B.	2016	Marine Pollution Bulletin			10-300Hz	

Ref #	Title	Author (s)	Year	Journal / Source	Species / Study Group	Survey Technique/ Source of Sound	Freq.	Intensity
50	Sound the alarm: A meta-analysis on the effect of aquatic noise on fish behavior and physiology	Cox, Kieran; Brennan, Lawrence P.; Gerwing, Travis G.; Dudas, Sarah E.; Juanes, Francis	2018	Global Change Biology				
51	The hearing of the Atlantic Salmon, Salmo salar	Hawkins, A. D.; Johnstone, A. D. F.	1978	Journal of Fish Biology	Atlantic Salmon (*Salmo salar*)	Cardiac Conditioning	380Hz	
52	Hearing in fish and their reactions to sounds from offshore wind farms	Wahlberg, Magnus; Westerberg, Håkan	2005	Marine Ecology Progress Series				
53	The Ear and Hearing in Sharks, Skates, and Rays	Casper, B. M.	2011	Encyclopedia of Fish Physiology				
54	Sound detection by the longfin squid (Loligo pealeii) studied with auditory evoked potentials: sensitivity to low-frequency particle motion and not pressure	Mooney, Aran; Hanlon, Roger T.; Christensen-Dalsgaard, Jakob; Madsen, Peter T.; Ketten, Darlene R.; Nachtigall, Paul E.	2010	Journal of Experimental Biology	Longfin squid (*Loligo pealeii)*		30-1000Hz	
55	The realtionship between body size and evoked potentials from the statocysts of the prawn Palaemon serratus	Lovell, J. M.; Moate, R. M.; Christiansen, L.; Findlay, M. M.	2006	Journal of Experimental Biology	Prawn (*Palaemon serratus)*	Lab based experiment	500Hz	125 dB re 1µPa

BlueWise Marine provides stakeholder engagement, marketing, communications, health and safety (HSEQ), fisheries monitoring and infrastructure management services for the marine and offshore renewable energy initiatives, projects and infrastructures.

BlueWise Marine is involved in a diverse array of marine projects in Ireland and Europe, such as offshore renewable energy, emerging technologies, marine test site and demonstration infrastructure, industry networks and the research and development market.

Our end-to-end approach to service delivery allows our clients to focus on their core business, while our team manages their assets and projects in a safe, efficient, socially inclusive and environmentally conscious manner.

Cover image credit: Aleksei Mzhachev / Unsplash.

Layout: Ekaterina Bessonova, BlueWise Marine.

BlueWise Marine Ltd.

ATU iHub Galway City,
Dublin Road, Galway, Ireland,
H91 DCH9

T: +353 91 394251
E: info@bluewisemarine.ie
W: bluewisemarine.ie

@BlueWise_Marine
BlueWise Marine