

STRIVE

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Assessment and Monitoring of Ocean Noise in Irish Waters

STRIVE

Environmental Protection
Agency Programme

2007-2013

Environmental Protection Agency

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EPA STRIVE Programme 2007–2013

**Assessment and Monitoring of Ocean Noise in
Irish Waters**

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STRIVE Report

Prepared for the Environmental Protection Agency

by

The Galway–Mayo Institute of Technology

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Table of Contents

<u>Disclaimer</u>	<u>ii</u>
<u>Acknowledgements</u>	<u>iii</u>
<u>Details of Project Partners</u>	<u>iv</u>
<u>Executive Summary</u>	<u>ix</u>
<u>1 Background and Objectives</u>	<u>1</u>
<u>1.1 Ocean Noise</u>	<u>1</u>
<u>1.2 Effects on Marine Life</u>	<u>3</u>
<u>1.3 Legislation</u>	<u>3</u>
<u>1.4 Aims and Objectives</u>	<u>5</u>
<u>2 Acoustic Inventory</u>	<u>6</u>
<u>2.1 Introduction</u>	<u>6</u>
<u>2.2 Methodology</u>	<u>6</u>
<u>2.3 Results</u>	<u>7</u>
<u>2.4 Discussion</u>	<u>8</u>
<u>3 Impulsive Noise from Seismic Surveys</u>	<u>11</u>
<u>3.1 Introduction</u>	<u>11</u>
<u>3.2 Register of Impulsive Noise from Seismic Surveys</u>	<u>14</u>
<u>3.3 Disturbance Area for Baleen Whales</u>	<u>17</u>
<u>3.4 Joint Register of Low and Mid-Frequency Impulsive Sound</u>	<u>24</u>
<u>3.5 Assessment of Seismic Surveys using Recommended Proxy</u>	<u>25</u>
<u>3.6 Recommendations</u>	<u>30</u>
<u>4 Assessment of Vessel Density</u>	<u>32</u>
<u>4.1 Introduction</u>	<u>32</u>
<u>4.2 Methods</u>	<u>33</u>
<u>4.3 Results</u>	<u>34</u>
<u>4.4 Discussion</u>	<u>44</u>
<u>4.5 Recommendations</u>	<u>45</u>
<u>5 Analysis of Indicator 11.2.1 Low Frequency Continuous Noise</u>	<u>46</u>
<u>5.1 Introduction</u>	<u>46</u>
<u>5.2 UPC LAB</u>	<u>46</u>
<u>5.3 Biospheric Engineering Ltd</u>	<u>50</u>
<u>5.4 Recommendations</u>	<u>51</u>
<u>6 Recommendations for Implementation of an Ambient Noise Monitoring Network in Irish Waters</u>	<u>52</u>
<u>6.1 Existing International Acoustic Monitoring Networks and Technologies</u>	<u>52</u>

6.2	Existing Irish Infrastructure	54
6.3	Equipment Appraisal	57
6.4	Protocol of Best Practice and Recommendations	58
7	Research Outputs	69
7.1	Publications	69
7.2	Conference Presentations	69
7.3	Recognition for Research Work	69
7.4	Outreach Programmes	69
7.5	Media Coverage (National and Regional)	69
8	Recommendations for Implementation and Uptake of Research Findings	71
	References	73
	Acronyms	80
	Appendix 1 Equipment Appraisal	83

Executive Summary

This desk study was aimed to help Ireland meet the requirements of the Marine Strategy Framework Directive (MSFD) (2008/56/EC) under Descriptor 11: *The introduction of energy, including underwater noise, is at levels that does not adversely affect the marine environment.* The main aim of the MSFD is that European seas achieve Good Environmental Status (GES) by 2020. By 2014, it is expected that all Member States will have established and implemented long-term monitoring programmes. Under Descriptor 11, two indicators have been developed with specific criteria in order to measure whether GES has been achieved. These indicators are 11.1.1, low and mid-frequency impulsive noise, and 11.2.1, low frequency continuous noise. To assist in the assessment of the indicators and facilitate the implementation of a long-term monitoring programme, the following project objectives were identified:

- Catalogue and describe acoustic data sets collected within the Irish Exclusive Economic Zone (EEZ) within the 10 Hz to 10 kHz band.
- Report on the existence of data sets that have been collected within the Irish EEZ at higher frequency bands.
- Create a register of licensed activities, within the Irish EEZ that contribute to ocean noise, focussing on seismic surveying.
- Assess and quantify seismic survey metadata from various sources to establish the proportion of days within a calendar year or defined period over a specified area in which target sounds are recorded ('bang days') and measured as sound exposure level or as peak sound pressure level at 1 m, within the 10 Hz to 10 kHz frequency band.
- Describe an approximate disturbance area for baleen whales.
- Collaborate with the UK in the creation of a joint register of licensed activities for Irish and UK

waters, focussing on seismic surveying contributing to regional reporting.

- Create a series of noise maps of seismic survey pressure in Irish waters across the years 2000–2011 based on equipment characteristics.
- Spatially map vessel density across the Irish EEZ using Vessel Monitoring System (VMS) data and Automatic Identification System (AIS) data.
- Deploy acoustic monitoring equipment and assess noise levels and evaluate the use of this technique as a means for Ireland meeting requirements under the MSFD.
- Present a conceptual framework for a network of ambient noise monitoring sites within the Irish EEZ.
- Explore monitoring strategies and assess potential technical solutions for a cost-effective noise monitoring programme in Irish waters.

[Chapter 1](#) provides an overview of biological, geophysical and anthropogenic noise sources and their implications for marine life. Marine fauna have coexisted for millions of years and it is likely that they have evolved to the presence of other biological and geophysical sounds adapting frequency and, in some cases, the temporal patterns of their acoustic niches. Without doubt, due to its recent and uncontrolled character, the introduction of anthropogenic noise at a large scale has conflicted with this balance, eliciting a range of physical, physiological and behavioural effects. This chapter also highlights current legislative agreements and policies in place for Irish waters, including the European Union Habitats Directive, the Wildlife Act (1976, amended 2000), the Bonn Convention (Conservation of Migratory Species of Wild Animals), the OSPAR Convention (Convention for the Protection of the Marine Environment of the Northeast Atlantic) and CITES (Convention on International Trade in Endangered Species).

The inventory of acoustic data sets collected in Irish waters detailed in [Chapter 2](#) was created to act as a reference library which is likely to facilitate in the assessment of ocean noise not only by providing information on acoustic data sets for analysis but also by highlighting geographical areas that have received little or no survey effort. Metadata from academic and research institutions were reported as well as those collected under the Marine Institute Foreign Observer Scheme and Passive Acoustic Monitoring (PAM) carried out on board seismic vessels for mitigation purposes. This study recommends that attempts should be made to continually log metadata on acoustic data collection within the Irish EEZ which may be used to inform future developments under the MSFD.

Two sources of anthropogenic noise were the focus of the assessment in this project: seismic surveying reported in [Chapter 3](#) and vessel traffic in [Chapter 4](#). Cetaceans have been continually highlighted as a high-risk group likely to suffer detrimental impacts and this project assessed spatial overlaps of seismic surveying with baleen whales and other cetacean species, using results from the seismic survey bang day analysis (STRIVE Report Series No. 96¹) and visual sightings data provided by the Irish Whale and Dolphin Group (IWDG). Of particular concern was the overlap highlighted between low-frequency cetaceans (baleen whales) along the south and south-west coast of Ireland (Q37, Q46, Q47, Q48, Q49, Q50, Q57 and Q58). Additionally, in a step towards collaborative monitoring under Descriptor 11, this project worked towards a common register of impulsive noise. Data of seismic surveys (UK Department of Energy and Climate Change (DECC) consent reference 2516, 2566, 2600, 2780, 2801 and 2908) conducted in UK waters in 2011 and 2012 were obtained from the Joint Nature Conservation Committee (JNCC) and the DECC in the UK and mapped alongside seismic surveys conducted in Irish waters during the same time frame. To further assess the power of seismic air guns,

1. Beck, S., O'Brien, J. O'Connor, I. and Berrow, S., 2012. *Assessment of Indicator 11.1.1: Register of Impulsive Noise from Seismic Surveys*. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland. http://www.epa.ie/pubs/reports/research/water/STRIVE_96_web.pdf

the project mapped surveys conducted in Irish waters between 2000 and 2011 in terms of the pressure amplitude in bar-m of the air-gun array used. Trends in peak-to-peak (P-P) pressure amplitude were variable throughout the years, with 2011 reporting the greatest P-P pressure amplitude of 161.2 bar-m. It was not always the case that the larger the volume of the air-gun array yielded, the greater the pressure amplitude. It is likely that a combination of analysis of the varying air-gun characteristics including the air-gun array volume as reported in STRIVE Report Series No. 96¹ and air-gun array P-P pressure amplitude would yield a more reliable indicator of seismic survey pressure. Recommendations include the continued assessment and quantification of seismic survey metadata in order to calculate the proportion of days that target sounds are recorded in an area and to continue spatial overlay with cetacean coastal and offshore sightings. It is also recommended to continue liaising with the JNCC to achieve regional reporting between Member States, Ireland and the UK. As noise produced in UK waters will travel into Irish waters, regional reporting will account for this.

Shipping analysis used VMS and AIS data sets to effectively assess vessel density across the Irish EEZ highlighting 'noisy' areas. Results highlighted high density areas along the east and south coasts, likely to be attributed to passenger ferries, and areas along the south coast and further offshore south and south-west within Ireland's EEZ, subject to high fishing vessel densities. Spatial overlaps between areas of high vessel density and low-frequency cetaceans occurred along the south and south-west coast of Ireland. Low-frequency cetaceans were also prevalent along the north-west continental shelf slope areas and slopes of the Porcupine Bank concurrent with high fishing vessel densities. It is recommended that VMS and AIS spatial analyses be repeated annually to continue to explore trends in Irish waters, highlighting noisy and quiet areas, and to continue to produce noise maps.

Assessment of Indicator 11.2.1 which forms [Chapter 5](#) was completed through external assistance by the Technical University of Catalonia (UPC) Laboratory of Applied Bioacoustics (LAB) based in Spain and Biospheric Engineering Limited based in Galway, Ireland. A long-term deployment was designed to

obtain a data set for analysis and to test the efficacy of the equipment provided by the UPC LAB in Irish waters (LIDO (Listen to the Deep Ocean Environment) equipment), while also providing the first real-time monitoring of noise in Irish waters and allowing for public participation through www.listentothedeep.com real-time access. The deployment location was positioned in a strong tide and the 63 Hz third octave band measurement was affected; the 125 Hz third octave band, however, had minimal interference. A ferry track consisting of 13 points was computed averaging over all available tracks in September using an omnidirectional source level from literature. For completeness, sound exposure level (SEL) estimations were made for the 125 Hz third octave band and over 1 day, based on ferry and other shipping traffic. Additionally, a number of short-term (15 min files) recordings were also carried out at a number of sites in busy ports and harbours using a system developed by Biospheric Engineering. Three locations were chosen: Dublin Bay, Galway Bay and the Shannon Estuary. Mean noise levels were reported as 113 ± 8.2 dB re 1 μ Pa for Dublin Bay, 103 ± 4.2 dB re 1 μ Pa for Galway Bay and 100 ± 7.5 dB re 1 μ Pa for the Shannon Estuary. This allowed for capacity to be developed within Ireland for the deployment of noise

monitoring equipment and technical solutions to be applied to strong tidal areas.

[Chapter 6](#) focuses on the development of the long-term noise monitoring programme and contains a review of existing noise monitoring programmes and available equipment and an assessment of strategies and technical solutions for a long-term noise monitoring programme specific to Irish waters. There is a considerable amount of existing infrastructure deployed in Irish waters from which ocean noise measurements could be made. There are several platforms deployed that routinely collect meteorological or oceanographic data, including the Irish Marine Weather Buoy Network, the Irish National Tide Gauge Network and the SmartBay Galway network. To assess suitable hardware and software, information was sought from acoustic equipment companies and institutions worldwide using a detailed questionnaire, taking into consideration cost analyses, equipment specification and capability, deployment recommendations, servicing requirements, technical solutions, software availability and customer service. Additionally, a detailed protocol for establishing a monitoring network in Ireland was designed by the UPC LAB and with implementation would allow Ireland to comply with the noise criteria defined under the MSFD.

1 Background and Objectives

1.1 Ocean Noise

Ocean noise has always existed, both in natural and biological forms. Past research on ocean noise levels has assessed natural geophysical sounds: precipitation, wave action, lightning, cracking ice and undersea earthquakes. Wave action can raise ocean noise levels by more than 20 dB in the 10 Hz to 10 kHz frequency band (Wilson et al., 1985), while precipitation can increase ocean noise levels by up to 35 dB across frequencies above 500 Hz to greater than 20 kHz (Richardson et al., 1995; NRC, 2003).

Biological noise is also emitted into the marine environment from various marine fauna. One of the best studied and notable biological contributions to marine noise comes from marine mammal vocalisations. These sounds cover a very wide range of frequencies, with dominant components between 20 Hz and 20 kHz (Richardson et al., 1995). Baleen whale (mysticete) vocalisations are significantly lower in frequency than are those of the toothed whales (odontocetes) with estimated auditory bandwidth extending to only 22 kHz (Southall et al., 2007). Mysticete vocalisations can be broadly categorised as low-frequency moans (of frequencies below 200 Hz), simple calls (impulsive, narrowband, peak frequency less than 1 kHz) and complex calls (broadband pulsatile signals) (NRC, 2003). Infrasonic signals in the 10–20 Hz range have been documented in the blue whale, *Balaenoptera musculus*, and the fin whale, *Balaenoptera physalus* (Richardson et al., 1995). Biological sound sources can significantly increase ocean noise levels and this contribution varies across many temporal patterns, for example along the west coast of the United States there have been recordings of blue whale choruses in September and October that have increased the ambient noise levels up to 20 dB (Cummings and Thompson, 1994). Many fish species are also known to produce sound for communication, feeding and swimming and in a variety of behavioural contexts, including reproduction, territorial defence, and aggression (Busnel, 1963; Zelick et al., 1999). Fish choruses are thought to play a role in spawning

behaviour (Holt, 2002) and have been found to increase ocean noise levels in various temporal patterns. The 'sunset chorus' that lasts for a few hours after sundown in the spring and early summer months can raise ocean noise levels by 20 dB or more between the 50 Hz and 5 kHz band over sustained periods of time (NRC, 2003). Another well-known source of biological noise from a few kilohertz to above 100 kHz in rocky bottom regions of shallow waters is from snapping shrimp (NRC, 2003). It has been reported that snapping shrimp sounds can have peak-to-peak (P-P) source levels up to 189 dB re 1 μ Pa at 1 m in frequencies reaching 200 kHz (Cato, 1992; Cato and Bell, 1992).

Sources of anthropogenic (man-made) noise that have come under recent scrutiny include noise emitted from activities such as shipping, seismic surveying, geophysical surveying, construction, oil drilling and production, dredging, sonar systems, acoustic deterrents and most recently from the construction and operation of renewable energy platforms. For assessment purposes, anthropogenic noise sources are often characterised as impulsive if their duration is brief, or continuous, or if the noise source persists for a prolonged time (Richardson et al., 1995). Shipping, a known continuous anthropogenic noise source, has been reported as the dominant source of anthropogenic sound in a broadband range from 5 to 300 Hz (NRC, 2003). The main cause of noise emitted from shipping is through propeller cavitation (Richardson et al., 1995). Characteristics of shipping noise, including frequency and source level, are roughly related to vessel size and speed, although this relationship is further complicated by vessel design and advances in ship technology (Richardson et al., 1995). Generally, it has been found that larger vessels emit lower frequency and louder noises (Richardson et al., 1995), with source levels from vessels in excess of 300 m length, reported as approximately 190 dB re 1 μ Pa at 1 m (Richardson et al., 1995). Ross (1993) reported an increase in ocean noise levels by 15 dB between 1950 and 1975 because of shipping. Andrew

et al. (2002) analysed ocean ambient noise data from 1994 to 2001 using a receiver on the continental slope off Point Sur, California. Noise levels recorded between 1994 and 2001 were found to exceed levels reported for 1963 to 1965 by approximately 10 dB within the 20–80 Hz and 200–300 Hz frequency bands. Andrew et al. (2002) speculated that this rise in noise levels could be due to increases in distant shipping. The west coast of Ireland has probably some of the less polluted regional seas in Europe; however, shipping is still likely to be the main source of continuous anthropogenic noise in Irish waters.

Marine dredging is also a known source of continuous noise in coastal waters which involves the excavation of sediment commonly used for the maintenance of shipping lanes. Sound emission is strongly influenced by sediment properties, whereby intense sounds can be emitted when excavating hard and cohesive sediment as a greater force is needed to dislodge the material (OSPAR, 2012). The main acoustic energy emitted from marine dredging is within 100 and 500 Hz and can be up to 180 dB re 1 μ Pa RMS (root mean square) pressure (Richardson et al., 1995). In most cases in Europe, it is standard practice that an Environmental Impact Assessment (EIA) is conducted prior to dredging activity providing information on intensity, duration and possible impacts of the specific case. Drilling has been classified as a source of low frequency continuous anthropogenic noise in the marine environment with broadband levels (10 Hz–10 kHz) of 124 dB re 1 μ Pa at 1 km (Blackwell et al., 2004).

Piledriving is a technique used in the construction of oil and gas platforms, wind farm foundations and harbour works which emits a low-frequency impulsive sound with peak energy between 100 and 200 Hz (OSPAR, 2009). Source levels can vary, reaching 243–257 dB (P-P) re 1 μ Pa at 1 m (Nedwell et al., 2004), and are dependent on a number of factors including the diameter of the pile. Seismic surveying and geophysical surveying involve sending high-energy directional sound sources to the ocean floor and measuring the reflected sound waves which can be analysed to determine geological features and hydrocarbon deposits. Seismic air guns are the most commonly used apparatus in Irish waters and are a key

concern assessing low and mid-frequency impulsive noise in the Irish marine environment. Source levels can reach up to 260–262 dB (P-P) re 1 μ Pa at 1 m with peak acoustic energy between 30 and 50 Hz (OSPAR, 2009). Sonar is a method used for locating and surveying in the marine environment. It has been noted as the first anthropogenic sound to be deliberately introduced to marine waters on a large scale (OSPAR, 2009). There has been increasing interest from the public and scientists on the effects of sonar on aquatic life with research studying possible links between mass stranding events and sonar activity. The majority of these cases have involved atypical mass strandings of beaked whales that were temporally and spatially coincident with naval mid-frequency sonars (2–10 kHz) and, to a lesser extent, air-gun arrays (Barlow and Gisiner, 2006). Sonars can operate in ranges from low to mid and even high frequencies exceeding 10 kHz. Military sonars operate in mid-frequencies between 2 and 10 kHz with source levels of 223–235 dB re 1 μ Pa at 1 m (OSPAR, 2009). Depth sounding sonars and fish finders operate mostly in higher frequencies between 24 and 200 kHz. Depth finding sonars have been reported with source levels of 220 dB re 1 μ Pa at 1 m at 15.5 kHz (Boebel et al., 2004). Marine renewable energy devices have become a recent source of anthropogenic noise in the ocean. The next decades will see increasing levels of offshore industrial development that will lead to increased amounts of noise pollution.

Marine fauna have coexisted for millions of years and it is likely that they have evolved to the presence of other biological and environmental sounds adapting frequency and in some cases, the temporal patterns of their acoustic niches. Pollution in the marine environment has been defined as “*the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of seawater, and reduction of amenities*” (GESAMP, 1983). Without doubt, due to its recent and uncontrolled character, the introduction of anthropogenic noise at a large scale has conflicted with this balance. Mitigating anthropogenic noise in this complex ecosystem is key to preserving the

balance and to continue utilising the world's oceans as a human resource. Most studies lack information on the long-term effects of noise sources on specific populations. There are few data available on current ambient noise levels in most regions and even less historical data. Information on trends is not available for any European waters. According to the Marine Mammal Commission (2007), underwater ambient sound levels will increase over time with more human activity (shipping, offshore construction) in the marine environment.

1.2 Effects on Marine Life

Anthropogenic ocean noise can elicit a range of physical, physiological and behavioural effects on marine fauna. Marine mammals are one of the more sensitive groups of marine species because they have a highly developed auditory system and use sound actively for feeding and for social communication. It is also known that marine mammals are vulnerable to the effects of habitat loss or reduced survival and reproduction rates. These damages could significantly impair the conservation of already endangered species that use acoustically contaminated areas for migratory routes, reproduction, and feeding. The vocalisations and estimated hearing range of baleen whales overlap with the highest peaks of acoustic energy of air-gun sounds and, consequently, these animals may be more affected by this type of disturbance than toothed whales (Southall et al., 2007). Similarly, the low-frequency component of shipping noise overlaps with the vocalisations and estimated hearing range of baleen whales, highlighting this group as high risk. There may be further long-term consequences due to chronic exposure. Furthermore, marine mammals are part of a larger ecosystem upon which they depend. Included in this ecosystem are other organisms, particularly fish and possibly marine reptiles and invertebrates that use sound in their normal behaviour and that may also be impacted by anthropogenic sounds (Richardson et al., 1995). These impacts include a reduction in the abundance of fish species of up to 50% in zones under exploration and a distinct range of physical injuries in both marine vertebrates and invertebrates.

For many reasons, evaluating the acoustic impact of artificial sound sources in the marine environment is a complex and expensive proposition. First, we face the relative lack of information on the sound-processing and analysis mechanisms in marine organisms. Although we are capable of cataloguing and recording the majority of these signals, we still do not know enough about the important role they play in the balance and development of populations. Secondly, the possible impact of sound emissions may not only concern auditory reception systems but might also interfere on other sensorial and systemic levels, possibly lethal for the affected animal. Complicating the situation even more is the fact that a prolonged or punctual exposure to a determined noise can have negative short, medium and long-term consequences not immediately observed. The lack of provision and research resources contributes to the greatest difficulty in obtaining objective data that will allow the efficient control of anthropogenic noise in the ocean. It should be further noted that the potential increase in ambient sound levels will not affect all areas equally but specific regions where offshore activity is high, e.g. some of the Exclusive Economic Zones (EEZs) around north-west Europe (OSPAR, 2009). Potential effects might not be proportionate to pollution levels due to variation in sound propagation and, most importantly, the distribution of marine life that is sensitive to sound.

1.3 Legislation

A number of existing legislations, relevant to Ireland, are in place to assess and mitigate the impacts of anthropogenic noise in the marine environment. The most relevant international policy is the European Union (EU) Marine Strategy Framework Directive (MSFD) (2008/56/EC). The main aim of the MSFD is that European seas achieve Good Environmental Status (GES) by 2020 (Fig. 1.1). Under this Directive, Member States hope to reach a balance between utilising the ocean as a natural resource and the ability to achieve and maintain good environmental status of marine waters.

GES will be assessed according to 11 descriptors, the eleventh of which encompasses anthropogenic ocean noise.

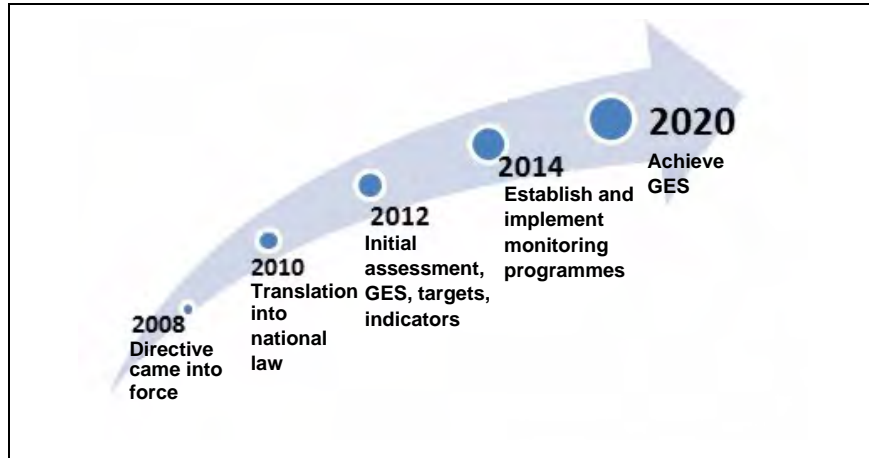


Figure 1.1. Timeline for the Marine Strategy Framework Directive (MSFD) (2008/56/EC). GES, Good Environmental Status.

As advised by the Commission (1 September 2010), under Descriptor 11, two indicators have been developed with specific criteria in order to measure whether GES has been achieved. These indicators are

- 11.1.1 Low and mid frequency impulsive noise, and
- 11.2.1 Low frequency continuous noise.

MSFD Descriptor 11

The introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

Criterion 11.1 *Distribution in time and place of loud, low and mid frequency impulsive sounds*

Indicator 11.1.1 *Proportion of days and their spatial distribution within a calendar year over areas of determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1 $\mu\text{Pa}^2\cdot\text{s}$) or as peak sound pressure level (in dB re 1 μPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz.*

Criterion 11.2 *Continuous low frequency sound*

Indicator 11.2.1 *Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1 μPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate.*

The problem faced by conservation actions is a lack of information about the effects of anthropogenic sound on marine species that will enable Member States to determine whether GES has been reached. There are a number of additional international and national legislations where the impacts of ocean noise are relevant. Under the Habitats Directive all cetacean species (Annex IV) and bottlenose dolphin (*Tursiops truncatus*), harbour porpoise (*Phocoena phocoena*), common seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) (Annex II) are entitled to strict protection to avoid disturbance to them and their habitats. Similar protection is provided under the Wildlife Act (1976, amended 2000) which prohibits hunting, injury, destruction of breeding places and wilful interference. The Bonn Convention (Conservation of Migratory Species of Wild Animals), the OSPAR Convention (Convention for the Protection of the Marine Environment of the Northeast Atlantic) and CITES (Convention on International Trade in Endangered Species) are legislative agreements in place to ensure protection and conservation of wildlife and their habitats. OSPAR aims to assess the quality of the marine environment and, through this central tenet, has released a number of documents relating to anthropogenic noise and its assessment under the MSFD (OSPAR, 2009, 2010).

1.4 Aims and Objectives

This project aimed to help Ireland meet the requirements of the MSFD under Descriptor 11 through assessment and monitoring of the two proposed GES indicators: 11.1.1 (loud, low and mid-frequency impulsive sounds) and 11.2.1 (continuous low frequency sounds). This was achieved through the following deliverables:

- Catalogue and describe acoustic data sets collected within the Irish EEZ within the 10 Hz to 10 kHz band.
- Report on the existence of data sets that have been collected within the Irish EEZ at higher frequency bands.
- Create a register of licensed activities, within the Irish EEZ, that contribute to ocean noise, focussing on seismic surveying.
- Assess and quantify seismic survey metadata from various sources to establish the proportion of days within a calendar year or defined period over a specified area in which target sounds are recorded ('bang days') and measured as sound exposure level (SEL) or as peak sound pressure level (SPL) at 1 m, measured within the 10 Hz to 10 kHz frequency band.
- Describe an approximate disturbance area for baleen whales.
- Collaborate with the UK in the creation of a joint register of licensed activities for Irish and UK waters, focussing on seismic surveying contributing to regional reporting.
- Create a series of noise maps of seismic survey pressure in Irish waters across the years 2000–2011 based on equipment characteristics.
- Spatially map vessel density across the Irish EEZ using Vessel Monitoring System (VMS) data and Automatic Identification System (AIS) data.
- Deploy acoustic monitoring equipment and assess noise levels and evaluate the use of this technique as a means for Ireland meeting requirements under the MSFD.
- Present a conceptual framework for a network of ambient noise monitoring sites within the Irish EEZ.
- Explore monitoring strategies and assess potential technical solutions for a cost-effective noise monitoring programme in Irish waters.

2 Acoustic Inventory

2.1 Introduction

It is suspected that ambient noise levels worldwide have been on the rise in recent decades with development in industry and, in particular, in commercial shipping. In the North Pacific, low-frequency background noise has approximately doubled in each of the past four decades (Andrew et al., 2002), resulting in at least a 15- to 20-dB increase in ambient noise. In recent years, interest has grown in the effects of anthropogenic noise on marine life (Richardson et al., 1995; NRC, 2003; Popper, 2003; Nowacek et al., 2007; Southall et al., 2007; Weilgart, 2007; OSPAR, 2009). There is specific mention of the assessment of annual trends in ambient noise as a means to measure GES of Indicator 11.2.1 Continuous low frequency noise.

A number of historical acoustic data sets recorded in Irish waters exist, so an inventory of where these are held and what information they hold will be a valuable compilation for present and future demands under the MSFD. With constant advances in acoustic modelling technology, these data sets will provide a reference library of historical acoustic data that can be assessed and have the potential to be used to determine noise levels or target sounds in particular locations within the Irish EEZ. Currently, the MSFD determines GES under Descriptor 11 through the assessment of low and mid-frequency sounds within the 10 Hz to 10 kHz band. It is anticipated that the assessment of high frequency sounds above this band will come into action in the coming years. Recent work by the Technical Sub Group (TSG) Noise highlighted high-frequency sounds as an area for future research and so historical data on frequencies outside of the current assessment criteria are also of interest. In Ireland, underwater acoustic monitoring has increased significantly in recent years (O'Brien et al., 2009). Passive Acoustic Monitoring (PAM) using towed hydrophones during opportunistic and dedicated cetacean surveys is now widely carried out (Gordon et al., 1999; de Soto et al., 2004; SCANS II, Cetacean Offshore Distribution & Abundance (CODA)) and fixed hydrophones have been used in the

Shannon Estuary to monitor bottlenose dolphins (Berrow et al., 2006; Hickey et al., 2009). Static Acoustic Monitoring (SAM) using T-PODs and C-PODs (click detectors) is widespread (Ingram et al., 2004; O'Brien et al., 2006; Philpot et al., 2007) and research into the use of underwater acoustic deterrents in the fishing industry has also taken place (Leeney et al., 2007; Berrow et al., 2009). Most recently, PReCAST (Policy and Recommendations from Cetacean Acoustics, Surveying and Tracking), a partnership between the Irish Whale and Dolphin Group (IWDG) and the Galway–Mayo Institute of Technology (GMIT) funded under the Sea Change Initiative by the Marine Institute and the National Parks and Wildlife Service (NPWS), aimed to assess cetacean habitat use acoustically, both offshore and acoustically, and therefore to inform management on recommended techniques and important habitats (O'Brien et al., 2013).

The collation or inventory of acoustic data sets collected in Irish waters will act as a reference library likely to facilitate in the assessment of ocean noise not only by providing information on acoustic data sets for analysis but also by highlighting geographical areas that have received little or no survey effort. It will:

- Catalogue and describe acoustic data sets collected within the Irish EEZ within the 10 Hz to 10 kHz band; and
- Report on the existence of data sets that have been collected within the Irish EEZ at higher frequency bands.

2.2 Methodology

Under the objectives defined in this project acoustic data sets collected within the Irish EEZ were catalogued and described. Emphasis was placed upon reporting data sets within the 10 Hz to 10 kHz bandwidth but acoustic data sets spanning higher frequencies were also reported and metadata are contained within the acoustic inventory. Emphasis was placed on acoustic data sets gathered as part of

cetacean monitoring either in a static mode (e.g. C-POD, T-POD and AQUAclick) or a passive mode (e.g. hydrophone).

Metadata acquisition involved an extensive literature review into specific research cruises and projects carried out in Irish waters. Metadata on acoustic files were gathered within the lead organisation – GMIT. The IWDG was contacted and asked to provide details of any archived acoustic data sets that it held at the time. To further supplement the acoustic inventory the contact details of Chief Scientists working through the Marine Institute Foreign Observer Scheme were obtained. Under this scheme, foreign states are required to apply for consent for their vessels to conduct marine scientific research activities in waters under Irish jurisdiction (including the Territorial Sea, 200 mile Exclusive Fishery Zone and the continental shelf). Under the United Nations Convention on Laws of the Sea (UNCLOS), the Marine Institute has the authority to place Irish Observers on foreign research vessels in Irish waters. All information stored electronically for the scheme was accessed (2006–2011). Chief Scientists were then contacted directly via the email address provided at the time of the survey. Additionally, a list of PAM surveys and associated details, carried out from any seismic survey conducted within the Irish EEZ from 2000 to the time of writing,

was obtained from the Petroleum Affairs Division (PAD).

2.3 Results

A full copy of the acoustic inventory can be found on the EPA Safer website. Acoustic data in the form of PAM and SAM from third-level colleges and research institutes were collected in Irish waters from 1993 to the time of writing. Acoustic work is ongoing in the Shannon Estuary cSAC (candidate Special Area of Conservation) and around the Mullet Peninsula, including work in Broadhaven Bay SAC in concurrence with the inshore construction phase of the Corrib Gas underwater pipeline. Areas previously surveyed include coastal areas of Galway Bay, the Shannon estuary cSAC, the Blasket Islands, Kilcredaun Point, Knockfinglas Point, the Mullet Peninsula, Broadhaven Bay SAC, Dublin Bay, Galley Head, Old Head of Kinsale, Sherkin Island, Castlepoint, Gleninagh, Clare Island, Calf Islands, Long Island and Kish Bank. Survey effort in the offshore has included areas of the Porcupine Bank, Porcupine Seabight, Whittard Canyon System, Celtic Shelf and Rockall Trough. Chief scientists from the Marine Institute Foreign Vessel Observer Scheme were contacted regarding surveys conducted within the Irish EEZ from 2006 to 2011 ([Table 2.1](#)).

Table 2.1. Summary of the Chief Scientist (CS) and survey details archived as part of the Marine Institute Foreign Vessel Observer Scheme, includes enquiries and responses conducted as part of this study.

	2006	2007	2008	2009	2010	2011	Combined
No. of surveys	20	34	25	28	35	24	166
% Surveys with named CS	80	0	0	100	100	100	63
No. of CSs	15	34	8	25	30	23	85
% CSs with email	33	88	75	60	63	91	69
No. CSs contacted	9	33 ¹	8 ¹	23 ¹	28 ¹	21	74
% Surveys enquired about	50	N/A	N/A	93	94	92	82
						Incorrect emails	8 (11%)
						CS replies	55 (74%)
						PAM (of CS replies)	7 (13%)

¹CS email from other survey years.
NA, not applicable.

Table 2.2. Summary of seismic surveys conducted in Irish waters between 2000 and 2011 that had a Passive Acoustic Monitoring (PAM) operator on board.

Survey ID	Company	Acquisition Contractor	Vessel	Area	Start date	End date
2003/02	PGS	PGS	M/V Geo Explorer	East Rockall Basin	19/07/2003	11/08/2003
2006/01	Shell	PGS	Ramform Viking	NE Rockall Basin	18/06/2006	31/07/2006
2011/02	Providence Resources	Polarcus	Polarcus Samur	Celtic Sea	09/06/2011	02/07/2011
2011/03	Lansdowne Celtic Sea	Polarcus	Polarcus Samur	Celtic Sea	02/07/2011	09/07/2011
2011/04	Lansdowne Celtic Sea	Polarcus	Polarcus Samur	Celtic Sea	09/07/2011	13/07/2011
2011/05	Lansdowne Celtic Sea	Polarcus	Polarcus Samur	Celtic Sea	13/07/2011	17/07/2011
2011/06	Providence Resources	Polarcus	Polarcus Samur	Porcupine Basin	19/07/2011	27/07/2011

The PAD of the Department of Communications, Energy and Natural Resources supplied information regarding PAM surveys conducted on board seismic vessels in Irish waters. Since 2000, there have been 44 seismic surveys conducted and, of these, seven have had a PAM operator on board (Table 2.2). The seven surveys collected acoustic data in the Celtic Sea, Rockall Basin and Porcupine Basin.

2.4 Discussion

Acoustic data in the form of PAM and SAM have been collected in Irish waters from 1993 to 2013, with work currently ongoing at a number of sites. The acoustic inventory contains metadata from inshore waters covering most of Ireland's coastline. Additionally, the acoustic inventory houses detailed information on data collected in waters of the Porcupine Bank, Porcupine Basin, Porcupine Seabight, Whittard Canyon System, Celtic Shelf, Rockall Trough, Rockall Basin and Celtic Sea. Marine research can be costly and any attempts to maximise information from existing data sets should be encouraged. Attempts should be made to continually log metadata on acoustic experiments to keep an up-to-date reference library for Ireland to use as a resource in the assessment and monitoring of ocean noise.

Under the Marine Institute Foreign Vessel Observer Scheme, a condition associated with the consent to conduct marine scientific research activities in waters under Irish jurisdiction is that the Chief Scientist, during the part of the cruise conducted within Irish waters, will submit within 1 week of the end of the cruise a short cruise narrative describing the cruise and its preliminary results to the Marine Institute in Galway. Subsequently, two copies of the full Cruise Report (including an assessment of the results of the cruise) and two copies of all publications arising out of the cruise must be provided to the Marine Institute. As part of the Foreign Vessel Observer Scheme, the Observer must also submit a cruise summary reporting on the research activities conducted by the vessel. It was found that few of these reports were archived at the Marine Institute and a significant proportion of the Chief Scientists did not provide an email contact.

Seismic surveys carried out in Irish waters authorised by the PAD do not require a PAM operator on board; however, surveys are required to adhere to the Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters published by the NPWS in 2007. Previous work has highlighted the advantages of PAM surveys for marine mammals over visual surveys which are largely

Summary of the NPWS Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters

- Applicable to all seismic surveys, multibeam and side-scan sonar surveys in bays, inlets or estuaries and within 1,500 m of the entrance of enclosed bays/inlets/estuaries or if so advised by the NPWS.
- Requires minimum distance of 100 km between adjacent seismic surveys in open water.
- Minimum source level required to achieve results should be used and frequencies chosen to minimise impacts on marine mammals.
- Qualified and experienced Marine Mammal Observers (MMOs) must be present on board all vessels conducting seismic (including boomers) or electromagnetic surveys at all times during the survey.
- The MMO must conduct a pre-start scan for marine mammals 30 min before the starting operations. A minimum distance of 1,000 m is required between the centre of the array/sound source and the nearest cetacean before starting operations. If marine mammals are seen within 1,000 m of the centre of the array/sound source the start of operations should be delayed until they have moved away, allowing 30 min after the last sighting for the animals to leave the area.
- In waters deeper than 200 m the pre-start scan and the operations delay after last sighting durations are increased to 60 min.
- Operations must carry out the required start-up procedure at all times including during testing of the sound source or if the sound source is stopped and not restarted for at least 5 min.
- The start-up procedure for multibeam and side-scan sonar surveys requires the sound level to be gradually built over a period of 20 min. Where this is not possible, the equipment should be turned on and off over a 20-min period.
- For seismic surveys the required start-up procedure allows achievement of maximum (or desired) output after 20–40 min. Power should be built up slowly from a low energy start-up (e.g. starting with the smallest air gun in the array and gradually adding in others) over at least 20 min.
- If turnaround time between sample lines or stations is greater than the time required to conduct a start-up procedure (30 min), then the sound source should be stopped and a full start-up procedure should be used prior to commencing the new line.
- After a break in firing of any duration, a visual check should be made for marine mammals within the 'exclusion zone'. If a marine mammal is present then recommencement of shooting should be delayed as per the instructions above.

dependent on observer bias, weather conditions and which can only be conducted in daylight hours (O'Brien et al., 2013). Increased PAM effort on board seismic surveys will create another valuable source of acoustic data that may be of use in further assessment of ocean noise.

2.4.1 Recommendations

The following recommendations have been devised as a result of this study:

- Attempts should be made to keep an up-to-date reference library of metadata on acoustic data sets collected in Irish waters.

- Future foreign vessel surveys should be required to submit both an electronic and a hard copy of the cruise report to the Marine Institute, including a contact email or postal address for the Chief Scientist, and this should be strictly enforced.
- PAM operators on board vessels conducting seismic surveys should be required to submit both an electronic and a hard copy of the cruise report to the PAD and the contracting company, including a contact email or postal address for the PAM operator.

3 Impulsive Noise from Seismic Surveys

3.1 Introduction

The MSFD has developed criteria under Descriptor 11 to define, identify and quantify anthropogenic sound sources. Increasing our biological knowledge is at the forefront of development in the assessment of anthropogenic noise and there is particular concern about the effects of ocean noise on marine life. There have been a number of recent reviews of the actual and potential impacts of sound sources on aquatic life (Hastings and Popper, 2005; IACMST, 2006). Recently, work has been published with a focus on particular sources of anthropogenic noise, encompassing low and mid-frequency impulsive sound (NRC, 2003; Nowacek et al., 2007; Southall et al., 2007; Weilgart, 2007; OSPAR, 2009).

Indicator 11.1.1 (low and mid-frequency impulsive sound) of Descriptor 11 under the MSFD (Tasker et al., 2010) primarily addresses noise emitted from seismic surveys, piledriving, acoustic deterrents, and the use of explosives. Seismic surveying is the primary technique used in the search for oil and natural gas reserves and has been highlighted as a major sound source of concern when assessing low and mid-frequency impulsive sound in Irish waters. A variety of geophysical equipment can be used in seismic surveys, including sparkers, boomers, pingers, chirp sonar and air guns. Sparkers, boomers and chirp sonar are all high-frequency seismic devices producing sounds between 0.5 and 12 kHz, with source levels of 204–210 dB (rms) re 1 μ Pa at 1 m (sparkers and boomers) and 210–230 dB re 1 μ Pa at 1 m (chirp sonar) (OSPAR, 2009). Air guns are commonly grouped into clusters or arrays, and can be mounted on a vessel or arranged in a device, towed along by a vessel. During operation, noise is emitted with source levels of 220–255 dB re 1 μ Pa peak at 1 m (Nowacek et al., 2007); the acoustic energy is strongest between 10 and 120 Hz but high-frequency sound of up to 100 kHz has been measured at low amplitudes. Air guns use pulses of compressed air to create impulsive broadband sound waves of ultra-short duration with high peak source levels (Nowacek et al.,

2007). The waves are directed downwards and, when reflected back up from the seabed, are detected by hydrophones; this information can then be analysed to assess the location and size of potential oil and natural gas deposits. Air guns are the most frequently used apparatus; they generate predominantly low-frequency sound and are the main source of concern for Ireland under Indicator 11.1.1. The sound generated during air-gun operation is within the detectable frequency range for many fish species (Popper and Fay, 1993; Slabbekoorn et al., 2010) and marine mammals (Au, 2000).

Seismic surveys are temporary and spatially localised in nature but noise from a single survey can filter through vast expanses of ocean. Sound emitted from a seismic survey conducted in the north-west Atlantic spanned a region of almost 160,935 km² (100,000 square miles), raising noise levels to 100 times higher than normal ambient noise levels continuously for days at a time (IWC, 2005). Furthermore, reverberations can cause 'ringing', continuously elevating background noise levels for much longer than the ultra-short duration noted for seismic air-gun sounds (Guerra et al., 2011). Reverberations alone were reported to increase background noise levels up to 128 km away from the source for one survey off the Alaskan North Slope (Guerra et al., 2011). Potential effects of anthropogenic noise are thought not to be proportionate to emission levels due to variation in sound propagation, cumulative effects and, most importantly, the distribution of marine life that is sensitive to sound. It is therefore important to utilise existing knowledge on the distribution and ecology of sensitive marine species. Complicating the situation even more is the fact that a prolonged or punctual exposure to a determined noise can have negative short, medium and long-term consequences not immediately observed. The challenge with the MSFD is to implement technological developments that combine the GES of the oceans with the interests of the industry.

Several studies have investigated the environmental impact of air-gun usage on marine mammals and, in particular, cetaceans (Richardson et al., 1986; Goold, 1996; Goold and Fish, 1998; McCauley et al., 1998; Finneran et al., 2002; Gordon et al., 2004; Stone and Tasker, 2006; Nowacek et al., 2007; Southall et al., 2007; Weilgart, 2007; Blackwell et al., 2008; Castellote et al., 2009; Gedamke et al., 2010; Cato et al., 2011). In 2005, the International Whaling Commission's (IWC) Scientific Committee concluded that increased sound specifically from seismic surveys was "cause for serious concern" (IWC, 2005). As cetaceans rely on sound as their primary sense for orientation, navigation, foraging and communication, anthropogenic sounds can impact in a number of ways that are dependent on sound frequency and intensity. There may be further long-term consequences due to chronic exposure, and sound can indirectly affect animals due to changes in the accessibility of prey, which may also suffer the adverse effects of acoustic pollution (Richardson et al., 1995). These damages could significantly impair the conservation of protected species that use acoustically contaminated areas for migratory routes, reproduction, and feeding.

Direct effects of seismic exploration as part of the oil and gas industry include changes in cetacean behaviour and distribution, and a distinct range of physical injuries. Stone and Tasker (2006) reported a reduced sighting rate of all cetacean species during periods of large-volume air-gun operation. A temporary shift in masked hearing thresholds has been reported for the beluga whale (*Delphinapterus leucas*) after exposure to seismic air-gun sounds (Finneran et al., 2002) and changes in vocalisation behaviour have been noted for a number of cetacean species, including bowhead whales (*Balaena mysticetus*) and common dolphins (*Delphinus delphis*), in response to seismic exploration (Goold, 1996; Blackwell et al., 2008). While there is higher frequency energy in the seismic pulses, the vocalisations and estimated hearing range of baleen whales overlap with the highest peaks of acoustic energy of air-gun sounds and, consequently, these animals may be more affected by this type of disturbance than toothed whales (Southall et al., 2007). There are 24 species of cetaceans known to occur in Irish waters, six of which are baleen whales (O'Brien et al., 2009). The fin whale

(*Balaenoptera physalus*) is the most commonly observed large baleen whale in Irish waters. Research on this species in the Mediterranean has reported changes in distribution and an avoidance of potential wintering grounds in response to seismic air-gun activity (Castellote et al., 2009). Results from a study conducted by Gedamke et al. (2010) suggested that baleen whales could be susceptible to a Temporary Threshold Shift (TTS) at 1 km or further from seismic surveys. Past research has recorded avoidance reactions from humpback whales (*Megaptera novaeangliae*) to seismic exploration (McCauley et al., 1998). Studies are ongoing in Australia, aiming to further understand and analyse the behavioural response of humpback whales to seismic surveys (Cato et al., 2011).

The acoustic properties of air-gun sounds emitted from seismic exploration and what is known of fish auditory thresholds indicate that marine fish species can hear air-gun sounds. Behavioural, physiological and indirect effects have been reported in a number of fish species in response to noise from seismic exploration, including alarm responses and changes in schooling patterns, position in the water column and swimming speeds (Pearson et al., 1992; Lokkeborg and Soldal, 1993; Wardle et al., 2001; Slotte et al., 2004; Boeger et al., 2006). McCauley et al. (2003) found evidence that the ears of fish exposed to air-gun operations sustained extensive damage to their sensory epithelia, with no apparent repair or replacement up to 58 days after exposure. Santulli et al. (1999) reported biochemical stress responses in the European sea bass (*Dicentrarchus labrax*) after exposure to air guns; stress hormones returned rapidly to normal levels within 72 h after exposure. Conversely, Popper et al. (2005) studied the possibility of a temporary threshold shift and found little impact of exposure to an air-gun array, of 750 cubic inches in volume, on the hearing of three fish species (*Esox lucius*, *Coregonus nasus* and *Couesius plumbeus*). Additionally, Wardle et al. (2001) found little impact of seismic air-gun operation on the day-to-day behaviour of the resident fish and invertebrates on an inshore reef. Many studies conducted on fish have focussed on how seismic prospecting affects fish abundance (Skalski et al., 1992; Pickett et al., 1994; Engås et al., 1996; Hassel et al., 2004; Slotte et al., 2004). In the Norwegian Sea,

Slotte et al. (2004) confirmed a change in depth distribution of blue whiting in the immediate vicinity after air-gun operation, while fish abundance increased in areas 30–50 km from the source. Similarly, Pearson et al. (1992) reported shifts in vertical distribution, changes in behaviour and the occurrence of startle and alarm responses of marine fish to seismic air-gun pulses along the Californian coast. Irish waters host many commercially important marine fish species and contain many critically important spawning areas for species including mackerel (*Scomber scombrus*), hake (*Merluccius merluccius*), herring (*Clupea harengus*), cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), plaice (*Pleuronectes platessa*) and sole (*Solea solea*) (Anonymous, 2009). Hirst and Rodhouse (2000) reviewed the detrimental effects on fisheries exposed to seismic surveying and noted the temporal and spatial limits of disturbance. Approximately 1.9 million tonnes of fish were taken by the EU fishing fleets in 2007 from the waters around Ireland (Anonymous, 2009); this industry is of great economic value to Ireland. Previous studies reported a decrease in catch per unit effort of 52% in hook and line fishing of rockfish species along the Californian coast (Skalski et al., 1992) and declines in trawl catches of both cod (*G. morhua*) and haddock (*M. aeglefinus*) in zones exposed to seismic air-gun firing in the Barents Sea (Engås et al., 1996). However, Pickett et al. (1994) were unable to determine a discernible effect on local catch rates of European sea bass (*D. labrax*) in an area exposed to seismic surveying.

The effects of noise on marine invertebrates have been studied to a lesser extent (Andriquetto-Filho et al., 2005; Parry and Gason, 2006; André et al., 2011). The Norway lobster (*Nephrops norvegicus*) is an important invertebrate in the Irish waters fishery industry, with average annual landings of 18,327 t between 2008 and 2010 (Marine Institute, 2011). Previous studies have investigated the hearing capabilities of cephalopods and crustaceans and it has been shown that the hearing ranges of some species overlap with the frequency range of seismic survey noise (Lovell et al., 2005; Hu et al., 2009; Mooney et

al., 2012). Therefore, the noise generated by air guns has the potential to cause detrimental impacts. André et al. (2011) recently documented fatal pathological impacts on the sensory hair cells of the statocysts in cephalopods in response to low-frequency sound. It is possible that marine invertebrates may be most sensitive to the vibrational component of sound and these statocyst organs provide a means of vibration detection (NSF, 2012).

3.1.1 Objectives

A number of objectives, listed below, were devised under the present project to assess and quantify the level of seismic activity at specific geographic locations within Irish waters in an attempt to assess the pressure of impulsive low and mid-frequency sounds across the Irish EEZ that will facilitate the Irish Government in fulfilling Ireland's requirements under the MSFD.

- Create a register of licensed activities within the Irish EEZ that contribute to ocean noise, focussing on seismic surveying.
- Assess and quantify seismic data from various sources to establish the proportion of days within a calendar year or defined period over a specified area in which target sounds are recorded ('bang days') and measured as SEL or as peak SPL at 1 m, measured within the 10 Hz to 10 kHz frequency band.
- Describe an approximate disturbance area for baleen whales.
- Collaborate with the UK in the creation of a joint register of licensed activities for Irish and UK waters, focussing on seismic surveying contributing to regional reporting.
- Create a series of noise maps of seismic survey pressure in Irish waters across the years 2000–2011 based on equipment characteristics.

A report published in 2012 as part of the present project aimed to assess the noise from seismic surveying, facilitating Ireland's ability to assess GES under Descriptor 11 (Beck et al., 2012). A summary is provided in [Section 3.2](#).

3.2 Register of Impulsive Noise from Seismic Surveys

Ireland is reported to import more than 80% of its gas requirements, increasing the pressure to discover indigenous natural gas and oil deposits. In the past decade, there has been a substantial rise in licence applications for offshore exploration and developments in Irish waters. The Irish Offshore Strategic Environmental Assessments (IOSEA) 3 and 4 produced by the PAD of the Department of Communications, Energy and Natural Resources reinforce this likely increase in seismic surveying noting an 'open-door' basis to licensing in the Irish and Celtic Seas (PAD, 2008, 2011). The scale of such surveys could have a likely impact on cetacean populations both coastal and offshore. A number of publications have been focussed on the effects of underwater sound produced from the oil and gas industry (Harris et al., 2001; Holt, 2002; Popper et al., 2005; Stone and Tasker, 2006; Genesis Oil and Gas Consultants, 2011; NSF, 2012). The MSFD GES TSG on Underwater Noise and other forms of energy proposes that Member States assess specific geographical areas subject to seismic exploration (Van der Graaf et al., 2012).

3.2.1 Methods

Details of seismic surveys conducted in waters under Irish jurisdiction from 2000 to 2011 were obtained from the PAD. These data included seismic activity occurring outside the Irish EEZ and the currently proposed MSFD boundary but within the currently designated Irish continental shelf in which the PAD authorises seismic exploration. The PAD divides the currently designated Irish continental shelf into quadrants of 1° latitude by 1° longitude and cell blocks of 10' latitude by 12' longitude, this is also used for analysis of seismic activity in the UK by the Department of Energy and Climate Change (DECC). This was deemed a suitable spatial scale for analysis of seismic activity under the MSFD Indicator 11.1.1.

Bang days were defined as "*days in which data from seismic surveying were acquired*". They were determined by the data acquisition dates provided by the PAD. Where acquisition dates were not available, dates with seismic data acquisition were assumed for

the entire survey duration. This is likely to be an overestimation of bang days, although instances of missing acquisition dates were minimal (7%) and so results obtained from this analysis are thought to be reliable and accurate. To determine the extent of seismic surveying in Irish waters and the locations under greatest surveying pressure, noise maps were generated across the years 2000–2011 through the ArcGIS (version 9.3) mapping software. If a survey spanned more than one cell block, then bang days per block were estimated as the total number of bang days divided by the total number of blocks for which the survey applied/spanned. This is likely to be an underestimation of survey effort for an individual cell block as most seismic surveys will occur in more than one cell block per day. Bang days per year were calculated as the sum of bang days across all surveys conducted within that year. Similarly, bang days across the entire study period were summed to create a noise map for 2000–2011.

The power of seismic air guns has increased over time as greater depths are explored and, as a result, the noise emitted by seismic exploration has increased. In the petroleum industry, air-gun volume is measured in cubic inches. To improve signal characteristics it is common to arrange several air guns in a cluster or array, with the guns so close together that they behave as a larger single gun. The air-gun array volume is the sum of the volumes of each gun, and is typically in the range 3,000–8,000 cubic inches. Larger volume arrays generally contain more air guns and so have a higher cumulative source level and are thus of a greater concern in the assessment of noise on the marine environment. Therefore, surveys conducted from 2000 to 2011 in Irish waters were also categorised based on the volume of the air-gun array. Noise maps were generated through the ArcGIS mapping software for each year; where more than one survey covered a cell block, the mean volume of the air-gun array used in the cell block was displayed.

3.2.2 Results

Between the years 2000 and 2011, a total of 44 seismic surveys were conducted in waters under Irish jurisdiction. Of these, 25 surveys were two-dimensional (2D) and 19 were three-dimensional (3D). The duration of 2D surveys during this time ranged

from 1 day to 51 days, with an average duration of 18 days. The duration of 3D surveys ranged from 4 days to 100 days, with an average of 31 days. For 2D seismic exploration, the number of cell blocks covered per day ranged from 0.11 to 4.67, with an average of 1.75 blocks per day. The more localised 3D seismic surveys covered 0.06–5.22 cell blocks per day, with an average of 0.72 cell blocks per day. The number of active authorisations has been steadily increasing since 2002, reaching a total of 42 active offshore authorisations and three active onshore authorisations in 2011 (Fig. 3.1). Analyses of seismic exploration between the years 2000 and 2011 revealed specific areas of interest to the oil and gas industry, namely quadrants Q11, Q12, Q18, Q19, Q25, Q27, Q43, Q48, Q49, Q50 and Q57 (Fig. 3.2). The year 2000 represented the highest number of surveys and the greatest pressure in terms of number of cells with bang days greater than 5. Analysis of the volume of air-gun arrays used in seismic surveys between 2000 and 2011 highlights a number of quadrants subject to larger arrays; these results were largely attributed to

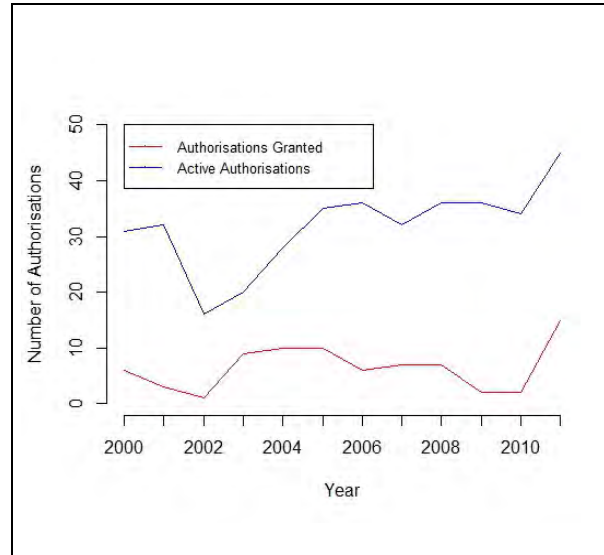


Figure 3.1. Offshore authorisations active for the period 2000–2011. This does not include two authorisations over the Helvick field in Cell Block 49/9. The total number of authorisations granted each year is shown in red. The total number of active authorisations for each year is shown in blue.

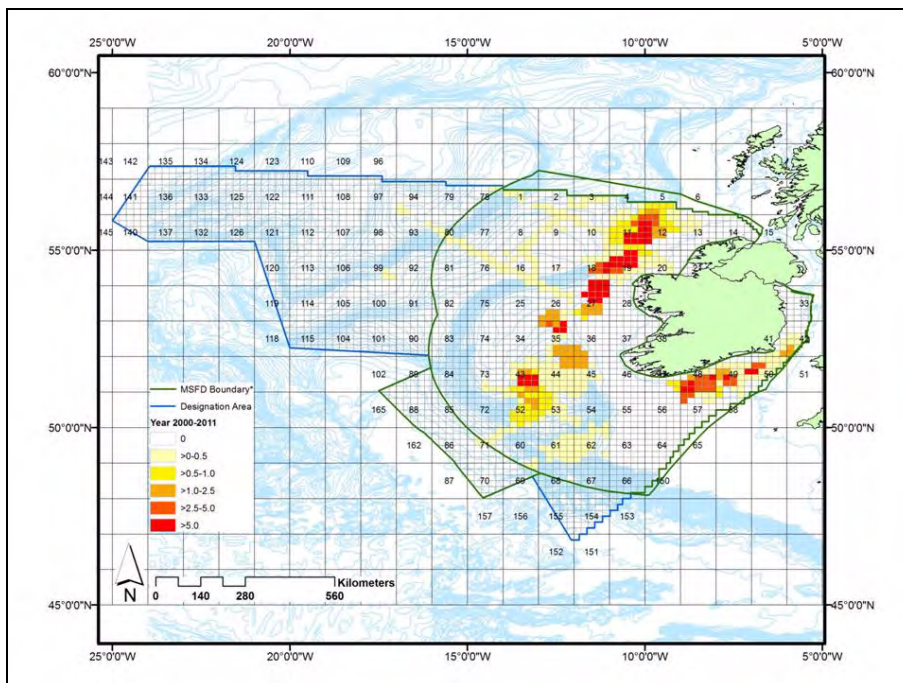


Figure 3.2. Seismic survey pressure in waters under Irish jurisdiction between 2000 and 2011. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colour representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

one large-scale 2D survey conducted in 2007, spanning 214 cell blocks using a large air-gun array of 7,440 cubic inches (Fig. 3.3). The most commonly used array volume in Irish waters between 2000 and 2011 was >3,000–4,000 cubic inches. The emergence of larger volume air-gun arrays occurred in 2007 and from this year onwards the volume of air-gun arrays used in seismic operations generally has been above the >3,000–4,000 category, the most commonly used volume across the entire period.

3.2.3 Discussion

The IOSEA 3 and 4 produced by the PAD estimate likely maximums of 49,000 km for 2D and 28,000 km² for 3D surveys between 2010 and 2016 in the Rockall Basin alone. The operation of ‘open-door’ licensing in the Irish and Celtic Seas estimated that a maximum of some 100,000 km for 2D and 30,000 km² for 3D will be surveyed between 2011 and 2020, by which point Ireland hopes to achieve GES under the MSFD. This report has highlighted specific geographical areas with the greatest frequency of seismic exploration in terms of cumulative bang days per cell block.

Seismic surveys that are 2D create infrequent bursts of impulsive noise, indicated by a low number of bang days but spanning a larger area, for example 0.17 bang days across 58 cell blocks for a 10-day survey using the results generated in this report, while 3D surveys produce frequent bursts of impulsive noise but within a localised area, for example 0.22 bang days across 15 cell blocks for a 10-day survey using the results generated in this report. Southall et al. (2007) reported the importance of multiple pulses in comparison with single pulses and recommended that cumulative SELs should be calculated in order to accurately determine if exposures exceed thresholds for physical damage to auditory systems in the form of TTS and Permanent Threshold Shift (PTS).

The results presented here also aim to develop an understanding of the varying intensities of air-gun arrays used across these geographical areas as previous work has documented responses varying with air-gun array volume. McCauley et al. (2000) observed humpback whales exposed to commercial seismic surveys with air-gun arrays of 2,678 cubic inches and

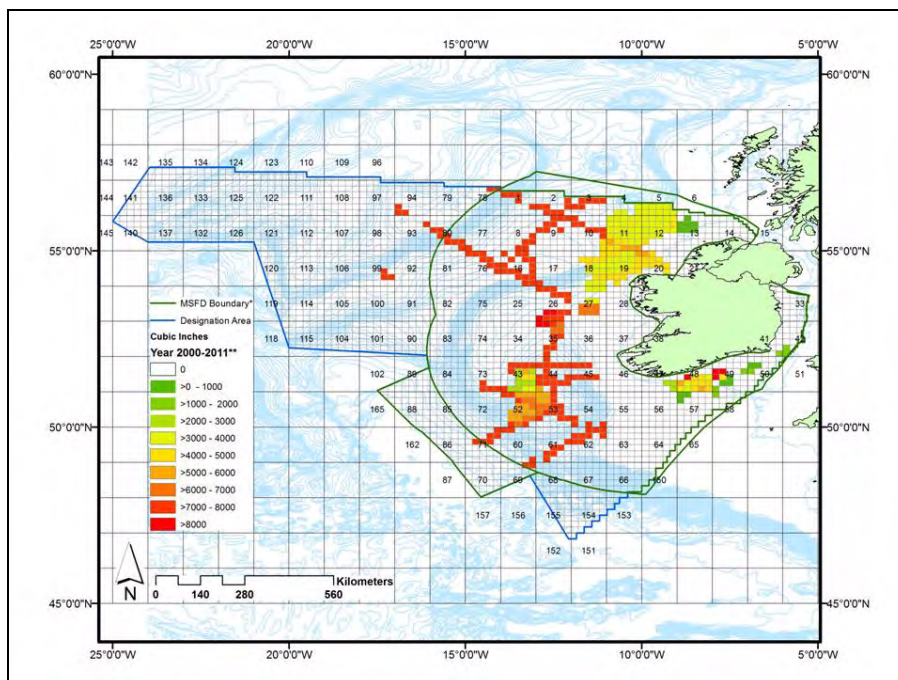


Figure 3.3. Seismic survey pressure in waters under Irish jurisdiction between 2000 and 2011. Mean volume of air-gun arrays, in cubic inches, used in each cell block is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

to experimental surveys with air-gun arrays of 20 cubic inches. They reported avoidance by the whales at received levels of 160–170 dB re 1 μ Pa from both arrays, with avoidance from the commercial array at a distance three times greater than for the smaller volume experimental array. Responses to single air guns and full air-gun arrays have also been documented in seals (Harris et al., 2001), reporting a greater avoidance during full-scale array usage. The next step is to assess the effects of noise from seismic exploration on marine life. Assessment must take into consideration the distribution of marine fauna in areas of highest pressure and determine the species of greatest concern both in terms of spatial and temporal overlap with seismic survey pressure but also in terms of vulnerability to increased noise emissions, current status of the population and life history parameters. Furthermore, it is imperative that some aspect of noise emissions for each survey is quantified to correctly assess Indicator 11.1.1 and to give an accurate representation of noise pressure from seismic surveying before deducing the extent to which marine fauna are affected.

3.3 Disturbance Area for Baleen Whales

Cetaceans have been continually highlighted as a high-risk group likely to suffer detrimental impacts from anthropogenic noise. This group has a highly developed auditory system and relies on sound as their primary sense for orientation, navigation, foraging and communication (Au, 2000). It is also known that marine mammals are vulnerable to the effects of habitat loss, with reduced survival and reproduction rates. There may be further long-term consequences due to chronic exposure, and sound can indirectly affect animals due to changes in the accessibility of prey, which may also suffer the adverse effects of acoustic pollution (Richardson et al., 1995). One of the most comprehensive reviews focussing on the impacts on marine mammals was that carried out by Southall et al. (2007) who presented noise exposure criteria and thresholds based on functional hearing group classifications leading to three groups: low-frequency cetaceans, mid-frequency cetaceans and high-frequency cetaceans (Table 3.1). Low-frequency cetaceans include those with an estimated auditory bandwidth of 7 Hz to 22 kHz and contain the baleen

whales. Mid-frequency cetaceans include those with an auditory bandwidth of 150 Hz to 150 kHz and contain most toothed whales. The high-frequency cetaceans include those with an estimated auditory bandwidth of 200 Hz to 180 kHz, which includes the harbour porpoise. The vocalisations and estimated hearing range of the baleen whales (low-frequency cetacean group) overlap with the highest peaks of acoustic energy of air-gun sounds and, consequently, these animals may be more affected by this type of disturbance than toothed whales (Au, 2000; Southall et al., 2007). However, physiological effects, including damage to tissue and gas bubbles or lesions, may occur irrespective of hearing capabilities. There are 24 species of cetaceans known to occur in Irish waters, six of which are baleen whales (O'Brien et al., 2009). In 1991, Ireland declared its coastal waters a whale and dolphin sanctuary, but this was not supported by any additional legislative instruments. However, Ireland is signatory to several relevant international conventions including the Bonn Convention (Conservation of Migratory Species of Wild Animals), the OSPAR Convention and CITES. Furthermore, there are a number national and international legislative agreements in place for the protection of cetaceans in Irish waters including the Whale Fisheries Act (1937) and the Wildlife Act (1976) which prohibits hunting, injury, destruction of breeding places and wilful interference. Most notable is the EU Habitats Directive (1992) which protects all cetaceans under Annex IV legally enforcing Ireland to achieve and maintain a favourable conservation status for these species. Translated into national law in 2010, the MSFD aims to achieve GES of European waters by 2020. It refers directly to the impacts of noise in the marine environment under Descriptor 11. The ability to define and monitor favourable conservation status under the Habitats Directive and GES under the MSFD remains a challenge, especially for Ireland considering the scale of the Irish EEZ which occupies an area eight times that of the landmass.

3.3.1 Methods

Assessing spatial overlaps with baleen whales and other cetacean species used results from the bang day analysis conducted in the register of impulsive noise from seismic surveys to investigate the spatial and

Table 3.1. Functional hearing group, estimated auditory bandwidth and the 24 species known to occur in Irish waters, represented in each group. Adapted from Southall et al. (2007).

Functional hearing group	Estimated auditory bandwidth	Species	Species common name
Low-frequency cetaceans	7 Hz to 22 kHz	<i>Balaenoptera acutorostrata</i>	Minke whale
		<i>Balaenoptera borealis</i>	Sei whale
		<i>Balaenoptera physalus</i>	Fin whale
		<i>Balaenoptera musculus</i>	Blue whale
		<i>Eubalaena glacialis</i>	North Atlantic Right whale
		<i>Megaptera novaeangliae</i>	Humpback whale
Mid-frequency cetaceans	150 Hz to 150 kHz	<i>Delphinapterus leucas</i>	Beluga
		<i>Delphinus delphis</i>	Short-beaked common dolphin
		<i>Globicephala melas</i>	Long-finned pilot whale
		<i>Grampus griseus</i>	Risso's dolphin
		<i>Hyperoodon ampullatus</i>	Northern bottlenose whale
		<i>Lagenorhynchus acutus</i>	Atlantic white-sided dolphin
		<i>Lagenorhynchus albirostris</i>	White-beaked dolphin
		<i>Mesoplodon bidens</i>	Sowerby's beaked whale
		<i>Mesoplodon europaeus</i>	Gervais beaked whale
		<i>Mesoplodon mirus</i>	True's beaked whale
		<i>Orcinus orca</i>	Killer whale
		<i>Pseudorca crassidens</i>	False killer whale
		<i>Physeter macrocephalus</i>	Sperm whale
		<i>Stenella coeruleoalba</i>	Striped dolphin
		<i>Tursiops truncatus</i>	Bottlenose dolphin
		<i>Ziphius cavirostris</i>	Cuvier's beaked whale
High-frequency cetaceans	200 Hz to 180 kHz	<i>Phocoena phocoena</i>	Harbour porpoise
		<i>Kogia breviceps</i>	Pygmy sperm whale

temporal overlap with cetacean presence. Visual cetacean sightings containing species identification, latitude, longitude, date and time data were obtained from the IWDG (Wall et al., 2013). These data were comprised from the following research programmes:

- Marine Mammals and Megafauna in Irish Waters – Behaviour, Distribution and Habitat Use;
- Irish Scheme for Cetacean Observation and Public Education (ISCOPE I and II);
- Cetaceans of the Frontier Survey 2009 and 2010 (Marine Institute Cruise Numbers CE0914 and CE10009); and
- IWDG Ferry Survey Programme and the IWDG Ship Surveys Programme.

Functional hearing groups of cetacean species previously categorised by Southall et al. (2007) based on estimated auditory bandwidth were taken into account during this analysis. Cetacean sightings were divided into low-frequency cetaceans, mid-frequency cetaceans and high-frequency cetaceans (Table 3.1). Southall et al. (2007) note that these weighting functions are based on a precautionary approach and therefore, in some cases, may overestimate the sensitivity of individuals.

Sightings databases were combined and formatted to remove any duplicate sightings and any sightings that could not be identified to a functional hearing group level were omitted, e.g. 'unidentified cetacean'. Effort-based maps of cetacean sightings were produced for each of the functional hearing groups. Effort and sightings data were assigned to the European

Environment Agency 50 km² reference grid using ARCMAP 10™ GIS software. Total survey effort (hours surveyed in sea state 0–6) per 50 km² were summed and mapped for each grid square as were total numbers of individuals counted per 50 km² for each cetacean class recorded during the surveys. Relative abundance was calculated as number of animals recorded per survey hour. Time-based analysis of relative abundance was used as it was judged to be more suitable than area-based analysis when amalgamating data from a variety of different survey platforms, travelling at different speeds (Reid et al., 2003).

Survey effort was graded based on sea state, with lower sea states being used for cetacean species that were difficult to detect and higher sea states for cetaceans with more readily visible sightings cues. Sea states 2 or less were used for high-frequency cetaceans, sea state 4 or less for mid-frequency cetaceans and sea state 6 or less for low-frequency cetaceans (Wall et al., 2013). Where non-effort-related sightings were recorded in a grid square (but no effort-related sightings occurred in that square), the grid square was marked positive for sightings (to facilitate distribution mapping), but no relative abundance value was assigned to that grid square.

The use of sea state in effort quantification is species specific and so combining data into functional hearing groups may cause issues with overstating the survey effort and, therefore, understating the relative abundance for some species. In the methodology presented here, the main concern is with the minke whale (*Balaenoptera acutorostrata*), using survey effort in sea states up to and including sea state 6 may understate the relative abundance as this species is more elusive than the larger baleen whales contained within the low-frequency cetacean group and is less likely to be observed in rougher sea conditions.

The data were plotted onto the ‘bang day’ map for seismic surveying in Irish waters between 2000 and 2011 presented in the register of impulsive noise from seismic surveys (Fig. 3.2).

3.3.2 Results

The combined visual cetacean sightings database contained sightings from 2004 to 2011, with a total of 10,770 sightings (Table 3.2). Of these, 2,466 sightings were identified as being in the low-frequency cetacean functional hearing group, 4,684 in the mid-frequency cetacean group, and 3,620 in the high-frequency cetacean group (Figs 3.4–3.9). From the combined database, 33% of the total records were of harbour porpoise sightings and 24% were of common dolphin sightings.

Table 3.2. List of species, number of visual sightings and associated functional hearing group contained within the ISCOPE and PReCAST combined database (Wall et al., 2013).

Species	Functional hearing group	Visual sightings
Blue whale	Low	2
Bottlenose dolphin	Mid	1,439
Common dolphin	Mid	2,628
Cuvier's beaked whale	Mid	1
Fin whale	Low	703
Fin/Sei/Blue whale	Low	54
Gervais beaked whale	Mid	0
Harbour porpoise	High	3,620
Humpback whale	Low	135
Killer whale	Mid	60
Minke whale	Low	1,237
Northern bottlenose whale	Mid	9
Pilot whale	Mid	173
Risso's dolphin	Mid	241
Sowerby's beaked whale	Mid	3
Sperm whale	Mid	72
Striped dolphin	Mid	5
Unidentified beaked whale	Mid	17
Unidentified baleen whale	Low	335
White-beaked dolphin	Mid	12
White-sided dolphin	Mid	24

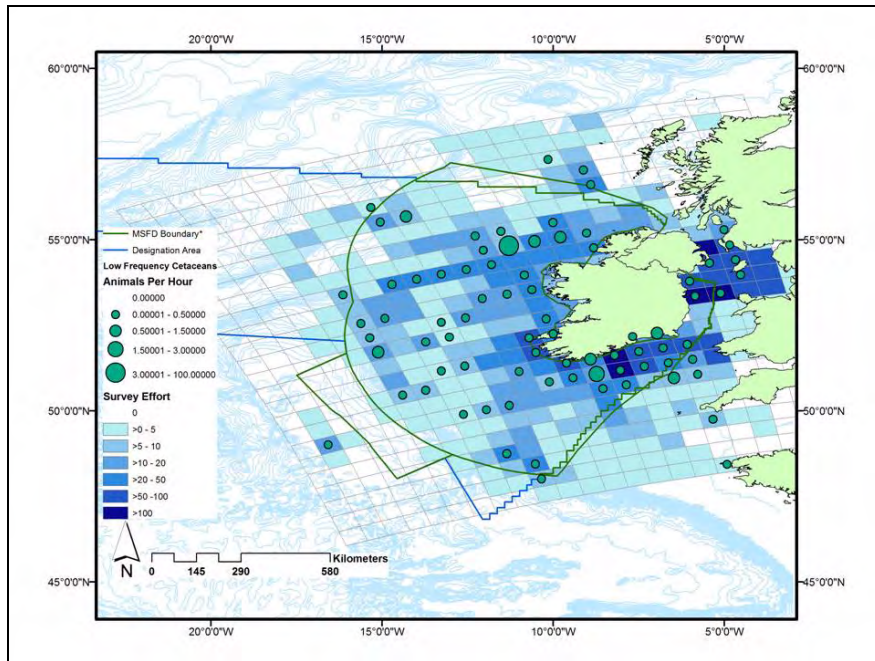


Figure 3.4. Total survey effort (hours surveyed in sea state 0–6) per 50 km² shown in a blue graduated colour scheme. Relative abundance, number of low-frequency cetaceans recorded per survey hour, shown in circular graduated symbols. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

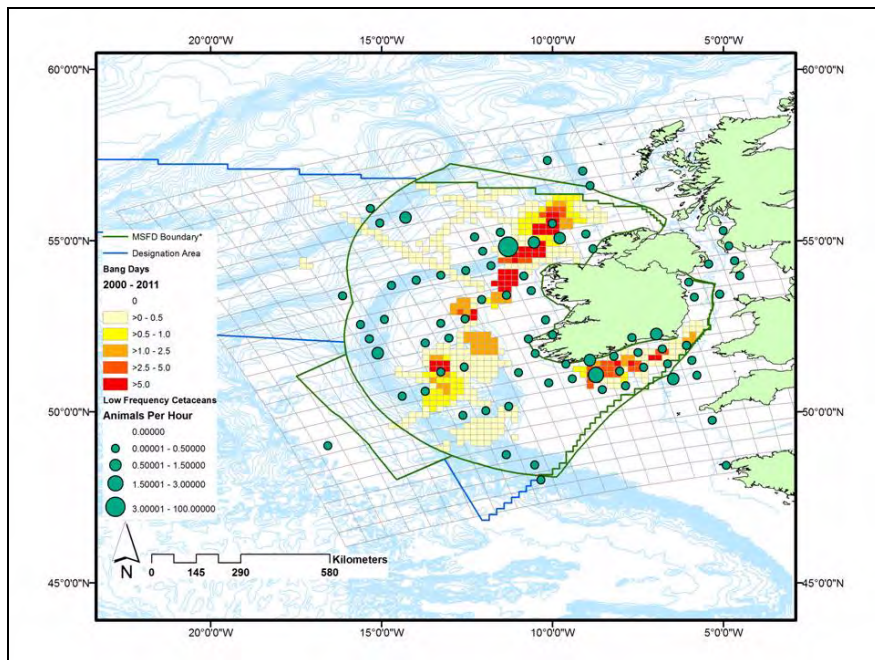


Figure 3.5. Seismic survey pressure in waters under Irish jurisdiction from 2000 to 2011, with relative abundance, number of low-frequency cetaceans recorded per survey hour, shown in circular graduated symbols. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

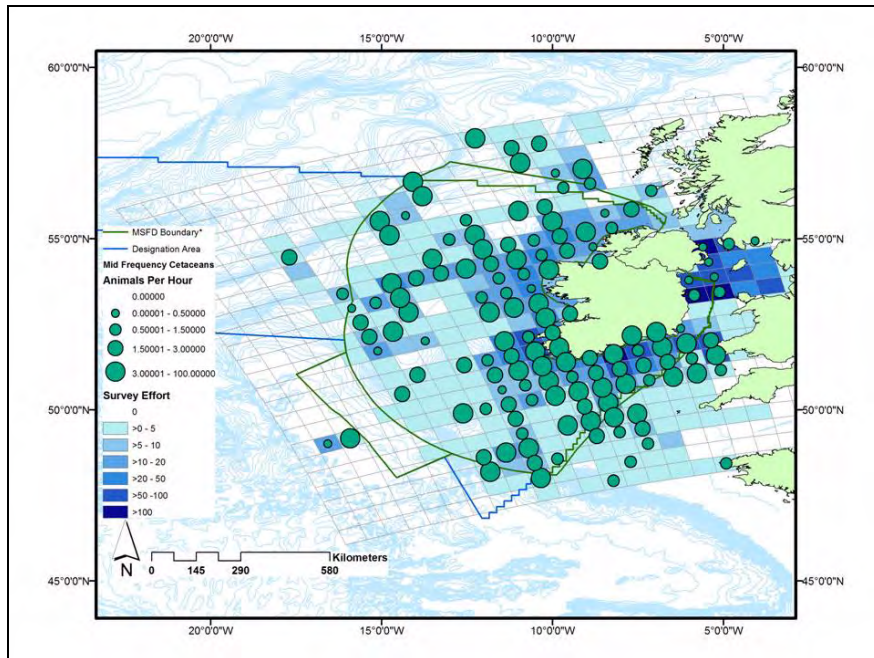


Figure 3.6. Total survey effort (hours surveyed in sea state 0–6) per 50 km² shown in a blue graduated colour scheme. Relative abundance, number of mid-frequency cetaceans recorded per survey hour, shown in circular graduated symbols. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

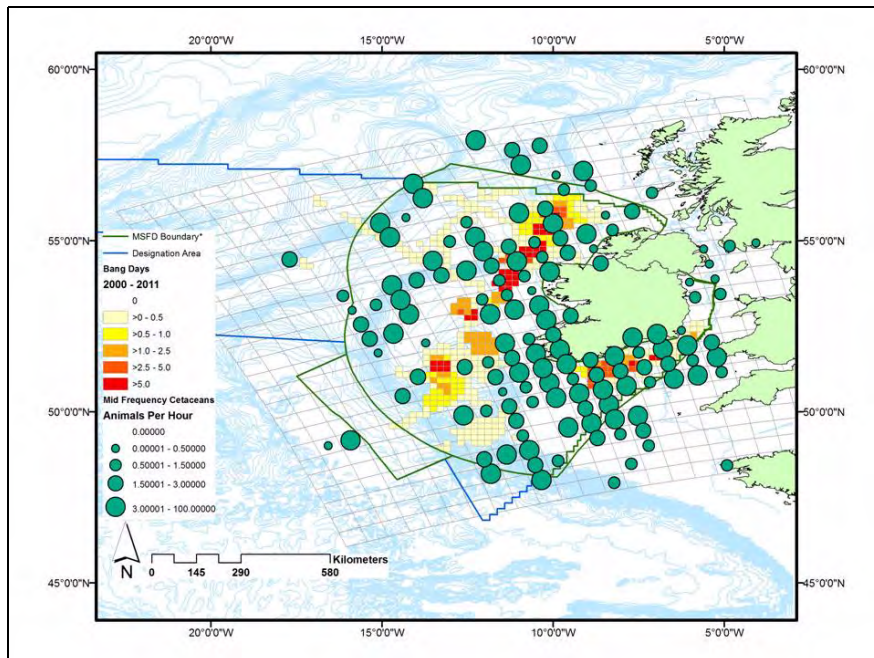


Figure 3.7. Seismic survey pressure in waters under Irish jurisdiction from 2000 to 2011, with relative abundance, number of mid-frequency cetaceans recorded per survey hour, shown in circular graduated symbols. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

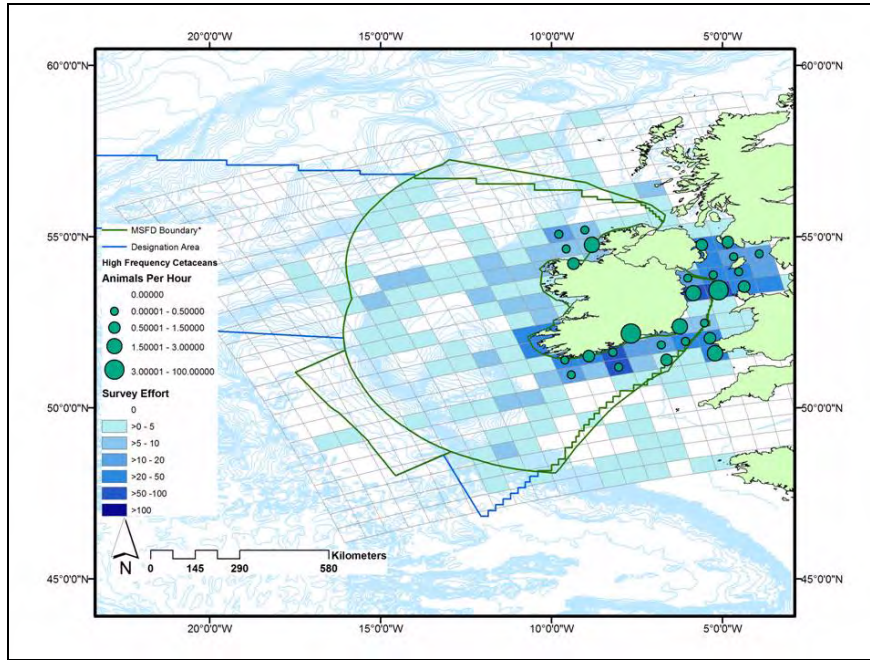


Figure 3.8. Total survey effort (hours surveyed in sea state 0–6) per 50 km² shown in a blue graduated colour scheme. Relative abundance, number of high-frequency cetaceans recorded per survey hour, shown in circular graduated symbols. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

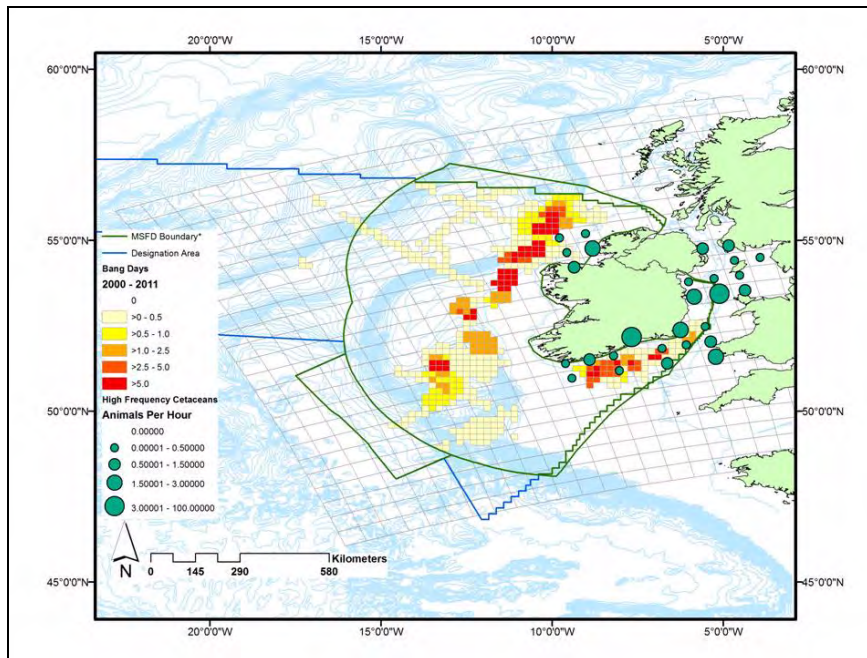


Figure 3.9. Seismic survey pressure in waters under Irish jurisdiction from 2000 to 2011, with relative abundance, number of high-frequency cetaceans recorded per survey hour, shown in circular graduated symbols. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

3.3.3 Discussion

Results of cetacean distribution areas highlight a number of spatial overlaps with areas of seismic surveying in Irish waters. There is overlap with the low-frequency cetaceans, as the auditory bandwidth of these species overlap with the frequencies of greatest amplitude from seismic air-gun arrays. Changes in fin whale and humpback whale distribution in response to seismic air-gun activity have been recorded (McCauley et al., 1998; Castellote et al., 2009). Gedamke et al. (2010) suggested that baleen whales could be susceptible to a TTS at 1 km or further from seismic surveys. Low-frequency cetaceans occurred along the south and south-west coasts of Ireland (Q37, Q46, Q47, Q48, Q49, Q50, Q57 and Q58), overlapping with areas with high seismic survey activity. A re-sightings rate of 18% has been reported for fin whales in coastal waters of the Celtic sea (Whooley et al., 2011). These occurrences have been previously attributed to the presence of spawning herring (Whooley et al., 2011). Low-frequency cetaceans were also prevalent along the north-west continental shelf slope areas and slopes of the Porcupine Bank (Q16, Q17, Q18, Q19, Q75, Q83 and Q84). In the assessment of noise from seismic surveys, Quadrants 12, 18, 19 and 27 are of particular importance with high relative abundances of low-frequency cetaceans and high numbers of bang days for 2000–2011.

Visual sightings of short-beaked common dolphins dominated the mid-frequency cetacean data set. Goold (1996) and Goold and Fish (1998) reported that common dolphins avoided the immediate vicinity during air-gun operation, indicating that localised disturbance may be a direct effect of seismic surveying. This species is Ireland's most widespread dolphin, and is abundant throughout the Irish EEZ. High densities have been reported for this species in seasonal foraging grounds along the south and south-west coasts in the summer and autumn (Wall et al., 2013). Of further interest is a number of deep-diving species contained within the mid-frequency cetacean group, including five beaked whale species from the Mesoplodon, Ziphius and Hyperoodon families and the sperm whale. Previous studies on beaked whales (MacLeod et al., 2006) have identified continental slopes, canyons and seamounts as areas of

particularly high abundance. Similarly, Wall et al. (2013) described beaked whale distribution in the Irish EEZ to be concentrated in slope and canyon habitats and the deeper waters of the Rockall Trough. Barlow and Gisiner (2006) reported on the impacts of anthropogenic noise on beaked whales and cited the use of air guns as one of the sound sources coincident with strandings. In particular, strandings of beaked whales from the *Ziphius* genus that occurred in the Galapagos in 2000 and in Mexico in 2002 were attributed to seismic surveys (Hildebrand, 2005).

The high-frequency cetacean data set comprises harbour porpoise sightings. The estimated auditory bandwidth of this species ranges from 200 Hz to 180 kHz (Richardson et al., 1995). The maximum acoustic energy emitted from seismic surveying is less than 300 Hz (Nowacek et al., 2007); it is not known how this type of anthropogenic activity interferes with the acoustic life of this high-frequency cetacean species but it may be susceptible to physiological damage and furthermore is likely to suffer from indirect effects on prey.

At present, mitigation measures devised by the NPWS for the protection of marine mammals during acoustic sea-floor surveys in Irish waters are in place (NPWS, 2007). Guidelines state that an MMO is required to be present on board the survey vessel to conduct observations 30 min before the onset of operation in waters of 200 m or less, and 60 min in waters deeper than 200 m. A soft start is recommended after the area has been confirmed clear of cetaceans, while exclusion zones of 1 km should be in operation. This practice assumes that animals will locate the source of the sound and will react appropriately to avoid exposure to potentially dangerous sound levels. These methods also depend on the detection of animals before seismic operations are at full intensity. Visual detection can be difficult for a number of species, for example harbour porpoise are particularly elusive and can go undetected visually for 95% of the time (Read and Westgate, 1995). The probability of detecting deep diving species including most beaked whales is low and drops rapidly in suboptimal survey conditions (Barlow, 1999). Most cetacean species produce sounds and one advantage of acoustic detection methods over visual methods is that these sounds can

often be detected when animals are submerged or out of range for visual observations, outside of daylight hours and in suboptimal survey conditions (O'Brien et al., 2013). Increasingly, attempts have been made to develop acoustic monitoring techniques rather than or simultaneous to visual methods. Several areas have been the target of seasonal acoustic monitoring on the west, south and east coasts of Ireland (Ó'Cadhlá et al., 2003; Ingram et al., 2004; Englund et al., 2006; Berrow et al., 2008, 2009; O'Brien, 2009; O'Brien et al., 2013). Moreover, seismic surveys conducted in Irish waters utilised PAM in 2003 and 2006; all surveys conducted in 2011 had a PAM operator on board.

Accurately predicting regions or periods where sensitive species are not present or present in low densities and authorising surveying with this scientific knowledge in mind will minimise exposure to anthropogenic noise and reduce the detrimental impacts of habitat loss. Coupling this with the current MMO and PAM soft-start methods is likely to be the most feasible and effective mitigation method.

3.4 Joint Register of Low and Mid-Frequency Impulsive Sound

The aim of the MSFD is to achieve GES of all European waters by 2020; this is independent of national boundaries and thus assessments by Member States should aim to acknowledge the waters of neighbouring Member States. Sound travels very efficiently in water and some low-frequency sounds can propagate over hundreds of kilometres. The assessment of ocean noise for individual Member States should therefore at least encompass adjacent waters which sound may originate from or spread to. Similarly, marine fauna that are sensitive to the impacts of noise are not necessarily sedentary in nature and annual migrations of some baleen whale species have been reported to span up to 10,000 km (Palsbøll and Berube, 1997). A number of legislative agreements and conventions on the protection and conservation of the marine environment to which Ireland is a party operate on the scale of ocean basins as opposed to the EEZ of Member States. The Bonn Convention on migratory species relies heavily on international co-operation and aims to link and co-ordinate efforts across the entire migratory range of a

species (CMS, 2011). The OSPAR Convention includes 15 governments of the western coasts and catchments of Europe which co-operate to protect the marine environment of the North-East Atlantic using five sub-regions (Arctic Waters, Greater North Sea, Celtic Seas, Bay of Biscay and Iberian Coast, and Wider Atlantic) and have released a document reporting on regional coherence for monitoring and assessment under the MSFD (OSPAR, 2012). The achievement of GES could benefit from the monitoring already in place under a number of these reporting schemes. Advice from the EU MSFD TSG on Noise suggests a common register for assessment of Indicator 11.1.1 through all Member States and so this project aimed to work towards a common register of impulsive noise from seismic surveying through collaboration with the UK.

3.4.1 Methods

Further details of seismic surveys conducted in UK waters were sought from the Joint Nature Conservation Committee (JNCC) and the DECC in the UK. These data included details of seismic surveys occurring in waters adjacent to waters under Irish jurisdiction. The DECC provided details on the latitude and longitude, dates of survey, acquisition dates, equipment specifications and the DECC consent reference (survey code). The PAD divides the currently designated Irish continental shelf into quadrants of 1° latitude by 1° longitude and cell blocks of 10' latitude by 12' longitude; this is also used for analysis of seismic activity in the UK by the DECC. This was deemed a suitable spatial scale required for analysis of seismic activity under the MSFD Indicator 11.1.1 as part of the joint register of impulsive noise.

Methods for the analysis of bang days followed that of the initial register of impulsive noise from seismic surveying completed by Ireland (Beck et al., 2012) and described in [Section 3.2](#) of this report. Noise maps were generated through the ArcGIS (version 9.3) mapping software. At the time of writing, it was understood that the JNCC was in the process of analysing seismic survey data from 2011 and 2012 for assessment under the MSFD (Paula Redman, JNCC, personal communication, 2013). The UK will also report on these surveys. Bang days from these surveys may be presented using different methods,

which may lead to differing results. The DECC consent references for seismic surveys conducted in UK waters have been included to facilitate cross-referencing between reports and publications.

3.4.2 Results and discussion

Data of seismic surveys (DECC consent reference 2516, 2566, 2600, 2780, 2801 and 2908) conducted in UK waters in 2011 and 2012 were obtained from the JNCC and the DECC in the UK. Surveys under DECC consent reference 2516, 2566 and 2600 conducted in 2011 are mapped in Fig. 3.10, with all seismic surveys conducted in Irish waters in 2011. This analysis forms a step towards collaborative monitoring between the UK and Ireland under Descriptor 11 of the MSFD. The project aimed to map seismic surveys conducted in UK waters over the same time frame as the seismic survey analysis (2000–2011) conducted for Irish waters but as the process is just under way in the UK, with a potentially large volume of surveys to be assessed, this wasn't possible at the time of report compilation.

3.5 Assessment of Seismic Surveys using Recommended Proxy

Potential impacts of noise from seismic surveying might not be proportionate to emitted noise levels. The transmission of sound in water is variable and site-specific and this will influence the distance to which organisms are influenced. Similarly, impacts will vary depending on the distribution of marine life that is sensitive to the sound. However, seismic surveys with a higher cumulative source level are of a greater concern in the assessment of noise on the marine environment. The power of seismic air guns has increased over time as greater depths are explored and, as a result, the noise emitted by seismic exploration has increased.

As reported by Caldwell and Dragoset (2000), the strength of an air-gun array is:

- Linearly proportional to the number of guns in the array;

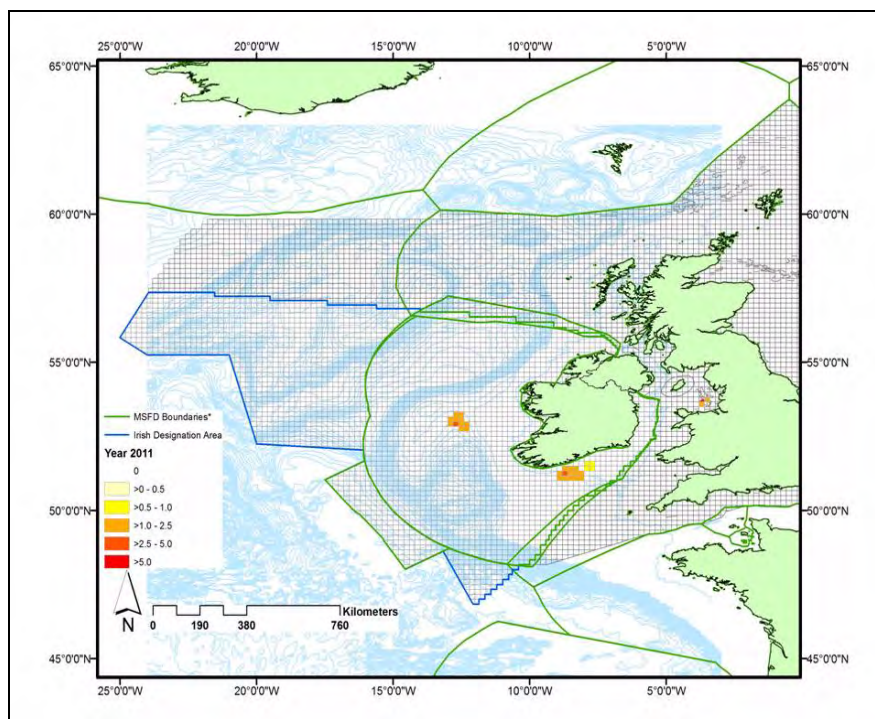


Figure 3.10. Seismic survey pressure in waters under Irish jurisdiction and surrounding UK waters in 2011. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colour representing the greatest number of bang days per cell. *MSFD Boundaries are the currently proposed boundaries under the Marine Strategy Framework Directive (MSFD) and are subject to change.

- Close to linearly proportional to the operating pressure of the array. A 3,000 psi (pounds per square inch) array has 1.5 times the amplitude of a 2,000 psi array; and
- Roughly proportional to the cube root of its volume.

The strength of seismic arrays is frequently measured over 0–125 Hz or 0–250 Hz. There may be a slight underestimation of total energy by these bandwidths, but the error is small because output above 250 Hz is limited. The acoustic signature of an air gun recorded by a hydrophone below the gun is characterised by two parameters: the primary pulse P-P pressure amplitude, measured in bar metres, and its bubble period, reported as the peak-to-bubble ratio (PBR). These parameters depend on the air-gun size, initial operating pressure, and depth (Dragoset, 2000).

The P-P pressure amplitude level is the maximum negative-to-positive measurement of the air-gun signature. To find the P-P strength of an array, the acoustic signature is measured at a distance vertically beneath the source where output signals of individual guns act as a single source. This distance is known as the far-field point. The acoustic signature at this distance is then used to define a nominal point-source level, at 1 m from the centre of the air-gun array (Landrø and Amundsen, 2010). Units are in bars at 1 m, abbreviated as bar-m. The actual level at this point is typically lower than the nominal level due to partial destructive interference between the signals of individual guns (Dragoset, 2000). A nominal source level of 100 bar-m means that if the air-gun array was a single point source a hydrophone placed 50 m vertically beneath the array would detect a pressure of 2 bar. The P-P pressure amplitude in bar-m can be converted to source level (L_s) in dB re 1 m Pa-m as follows (Landrø and Amundsen, 2010):

$$L_s \text{ (dB re 1 m Pa-m)} = 20 \log_{10} (\text{P-P}) + 220 \quad \text{Eqn 3.1}$$

The EU MSFD TSG on Noise suggested the pressure amplitude in bar-m as a suitable characteristic of seismic air-gun arrays to be used in the assessment of noise from seismic surveying under Indicator 11.1.1 of MSFD Descriptor 11. The present project aimed to map seismic surveys conducted in Irish waters

between 2000 and 2011 in terms of the pressure amplitude in bar-m of the air-gun array used.

3.5.1 Methods

Further details of seismic surveys conducted in waters under Irish jurisdiction from 2000 to 2011 were obtained from the PAD of the Department of Communications, Energy and Natural Resources. These data included seismic activity occurring outside the Irish EEZ and the currently proposed MSFD boundary but within the currently designated Irish continental shelf in which the PAD authorises seismic exploration. Additionally, contact details were sought for acquisition companies of surveys conducted between 2000 and 2011 for which the PAD did not hold information on the intensity of the air-gun arrays used in terms of bar metres. Surveys for which the pressure amplitude could not be determined were removed from the data set.

Quadrants of 1° latitude by 1° longitude and cell blocks of 10' latitude by 12' longitude, currently used by the PAD and the UK DECC, were used as a suitable spatial scale for analysis of seismic activity under the MSFD Indicator 11.1.1.

3.5.2 Results and Discussion

Differences in array volumes, in cubic inches, across seismic surveys conducted in Irish waters between 2000 and 2011 have been analysed and discussed in [Section 3.2](#) (see also Beck et al., 2012). The operating pressure in pounds per square inch is often given in acquisition reports and marine mammal observer reports for seismic surveys conducted in Irish waters. The majority of surveys conducted in Irish waters between 2000 and 2011 reported full power operating pressures of 2,000 psi. Two surveys reported operating pressures of 2,500 psi. While the number of air guns available for a given survey is often reported, the actual number used during operations is rarely confirmed and so an effective analysis of this characteristic could not be conducted. Seismic surveys conducted in Irish waters between 2000 and 2011 were mapped in terms of the pressure amplitude in bar-m of the air-gun array used ([Figs 3.11–3.17](#)).

Trends in P-P pressure amplitude were variable throughout the years; both 2000 and 2008 reported the

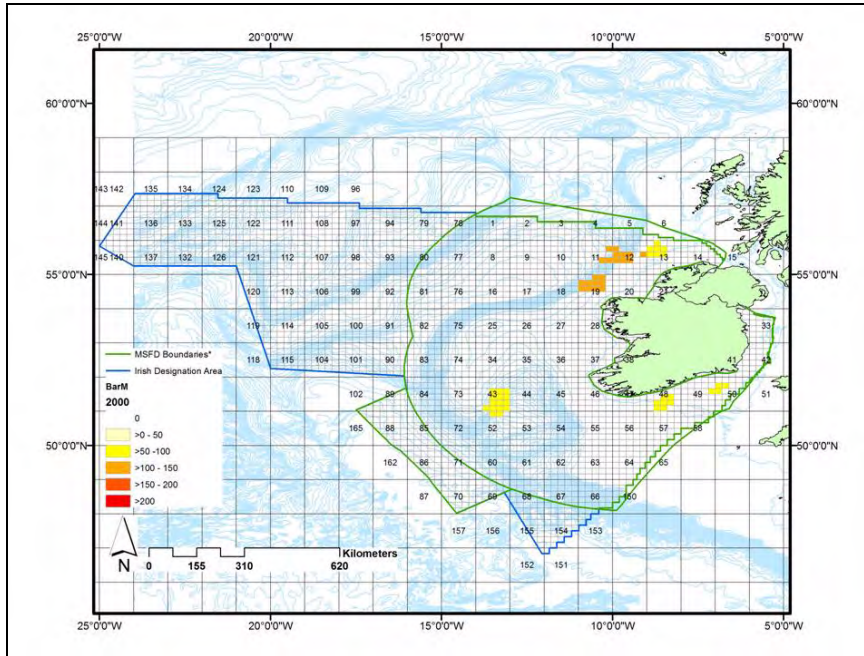


Figure 3.11. Seismic survey pressure in waters under Irish jurisdiction for the year 2000. Peak-to-peak pressure amplitude, in terms of bar metres, is shown in a graduated colour scheme with darker colours representing greater pressure amplitudes. Note: three of 11 surveys in 2000 did not report bar metres and have been removed from the data set. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

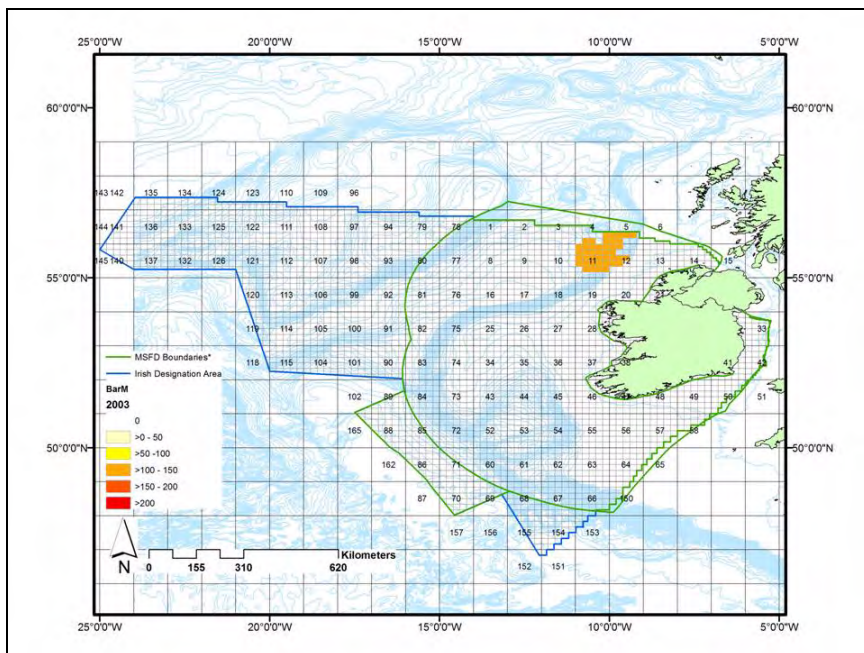


Figure 3.12. Seismic survey pressure in waters under Irish jurisdiction for the year 2003. Peak-to-peak pressure amplitude, in terms of bar metres, is shown in a graduated colour scheme with darker colours representing greater pressure amplitudes. Note: two of three surveys in 2003 did not report bar metres and have been removed from the data set. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

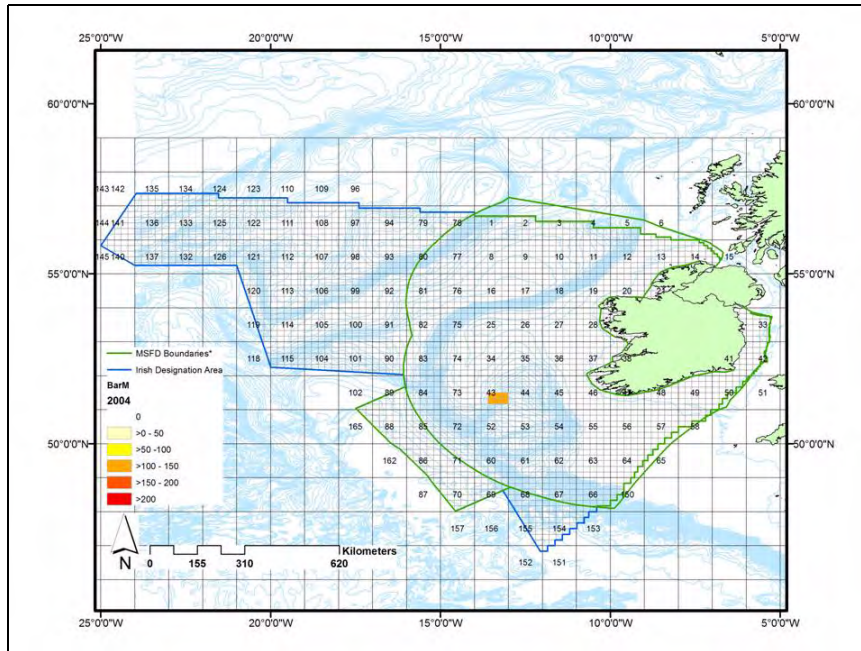


Figure 3.13. Seismic survey pressure in waters under Irish jurisdiction for the year 2004. Peak-to-peak pressure amplitude, in terms of bar metres, is shown in a graduated colour scheme with darker colours representing greater pressure amplitudes. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

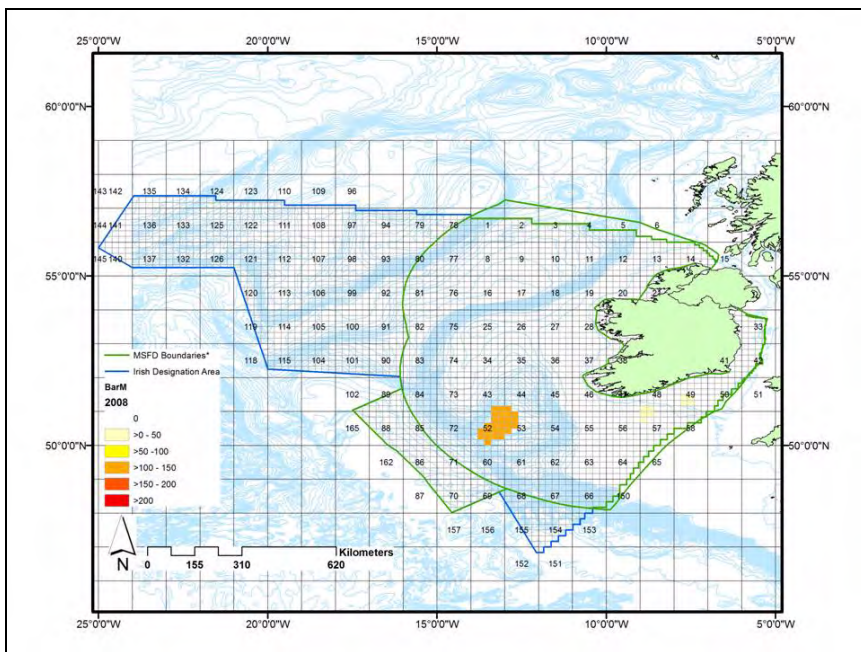


Figure 3.14. Seismic survey pressure in waters under Irish jurisdiction for the year 2008. Peak-to-peak pressure amplitude, in terms of bar metres, is shown in a graduated colour scheme with darker colours representing greater pressure amplitudes. Note: one of four surveys in 2003 did not report bar metres and has been removed from the data set. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

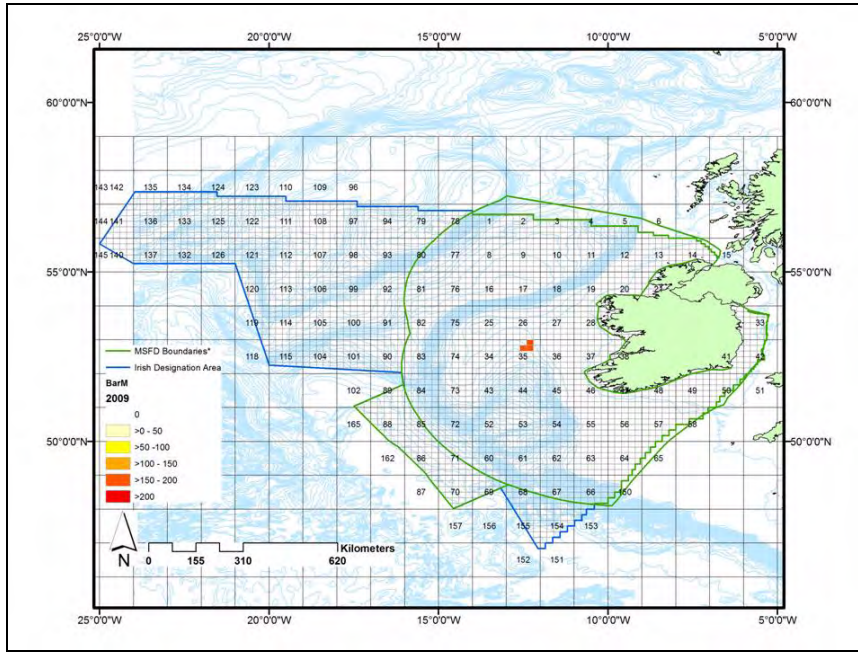


Figure 3.15. Seismic survey pressure in waters under Irish jurisdiction for the year 2009. Peak-to-peak pressure amplitude, in terms of bar metres, is shown in a graduated colour scheme with darker colours representing greater pressure amplitudes. Note: one of three surveys in 2009 did not report bar metres and has been removed from the data set. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

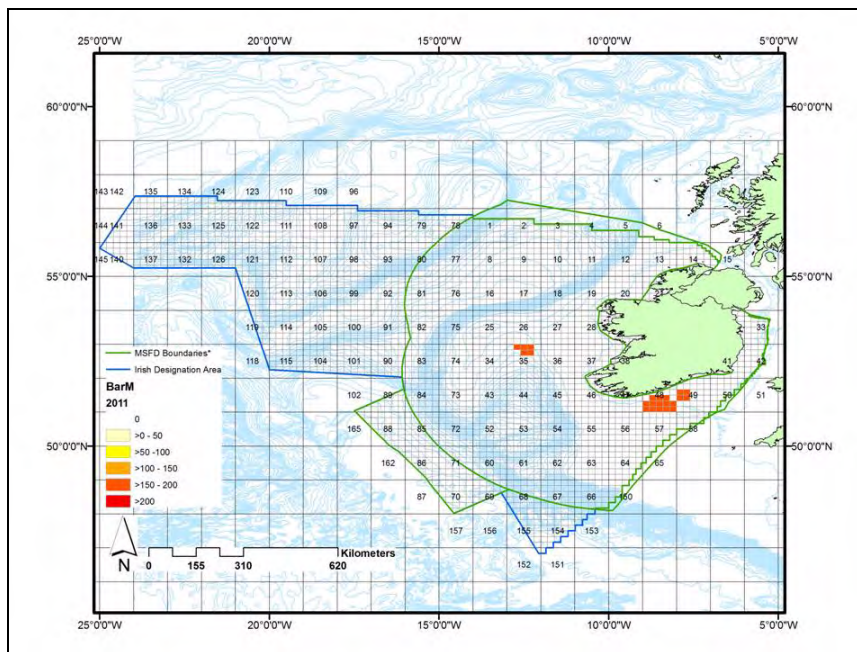


Figure 3.16. Seismic survey pressure in waters under Irish jurisdiction for the year 2011. Peak-to-peak pressure amplitude, in terms of bar metres, is shown in a graduated colour scheme with darker colours representing greater pressure amplitudes. Note: one of six surveys in 2011 did not report bar metres and has been removed from the data set. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

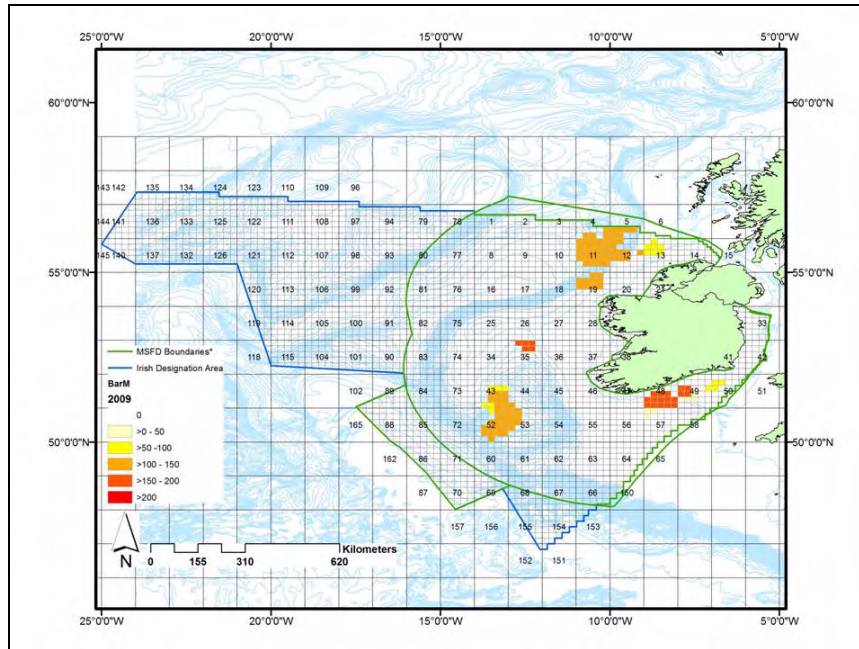


Figure 3.17. Seismic survey pressure in waters under Irish jurisdiction for the years 2000–2011. Peak-to-peak pressure amplitude, in terms of bar metres, is shown in a graduated colour scheme with darker colours representing greater pressure amplitudes. Surveys that did not report bar metres have been removed from the data set. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

lowest values of 67 and 18 bar-m, respectively. The greatest P-P pressure amplitude was reported in 2011, with a value of 161.2 bar-m. Of the six surveys conducted in 2011, five used the same vessel and equipment set-up.

Analysis of the P-P pressure amplitude for seismic surveys between 2000 and 2011 highlighted a number of quadrants subject to higher noise levels. These results, however, only report on 20 out of 44 seismic surveys that were conducted. Based on the available literature, it was observed that air-gun array volume in a given survey was stated but the pressure amplitude was less commonly reported. It is difficult to draw conclusions based on the data presented here. However, Quadrants 48 and 49 along the south coast of Ireland are of particular concern in this analysis. Previous analysis of bang days (Section 3.2) and the spatial overlap with baleen whale distributions (Section 3.3) also highlighted these quadrants as areas for concern. It was not always the case that the larger the volume the air-gun array yielded, the greater the

pressure amplitude, and differences can be seen between Figs 3.3 and 3.17. It is likely that a combination of analysis of the varying air-gun characteristics would yield a more reliable indicator of seismic survey pressure.

3.6 Recommendations

There were a number of limitations on this assessment and as a result the following recommendations have been devised:

- Attempts should be made to keep an up-to-date register of licensed activities emitting low and mid-frequency impulsive sound.
- The bang day analysis can be repeated for subsequent years to monitor the annual trend in seismic survey pressure in Irish waters.
- Future assessment could look into the use of hours as opposed to bang days. This timescale may provide a more informative analysis.

- Attempts should be made to continue contact with the JNCC on its seismic data analysis and encourage joint reporting by Member States.
- Future seismic surveys should be required to submit both an electronic and a hard copy of the survey report to the PAD, including detailed information on the equipment specifications, equipment set-up and a log of daily operations. This should be strictly enforced.
- PAM operators on board vessels conducting seismic surveys should be required to submit both an electronic and a hard copy of the cruise report to the PAD, including a contact email or postal address for the PAM operator.

4 Assessment of Vessel Density

4.1 Introduction

Shipping has long been recognised as the dominant source of underwater noise at frequencies below 300 Hz (Ross, 1976; Hildebrand, 2005). However, research and public concern on the impacts of anthropogenic noise have tended to focus on high-energy impulsive sound sources that have been associated with immediate physiological and behavioural effects. Increasingly, concerns have expanded to include continuous, lower energy sources which propagate efficiently across ocean basins and may cause more insidious impacts. Commercial shipping has increased in terms of numbers and size and is producing ever increasing amounts of underwater noise. In the North Pacific, low-frequency background noise has approximately doubled in each of the past four decades (Andrew et al., 2002) resulting in at least a 15- to 20-dB increase in ambient noise. Local effects have also been documented – Gervase et al. (2012) reported that ferry traffic added 30–35 dB to ambient levels above 1 kHz during crossings and Amoser et al. (2004) noted a rise in ambient noise levels which reached up to 128 dB re 1 μ Pa SPL at a distance of 300 m from motorboats.

Noise pollution generated by commercial and recreational boat traffic has the potential to cause behavioural effects in many marine species. Sara et al. (2007) reported that local noise pollution generated by boats produced behavioural deviations in tuna schools, including change in direction, unconcentrated and uncoordinated school structure. Behavioural responses including avoidance reactions were observed in herring and cod in response to playbacks of vessel noise (Engås et al., 1995). Soto et al. (2006) reported an unusual foraging dive in a Cuvier's beaked whale coinciding with a passing large ship. Behavioural disturbance at distances of up to 5.2 km have been documented for beaked whales when exposed to broadband shipping noise (Pirrotta et al., 2012). The effect of whale-watching tour boats has been studied to a greater extent in recent years due to concerns regarding this rapidly expanding industry

(Hoyt, 2001). Arcangeli and Crosti (2009) concluded that tour boat presence influenced the population structure and the duration and frequency of behavioural states in the bottlenose dolphin. Lundquist et al. (2012) reported similar findings for the dusky dolphin. Christiansen et al. (2010), Lusseau (2003) and Mattson et al. (2005) also reported changes in behaviour of *Tursiops* species when exposed to tour boats but Mattson et al. (2005) noted that larger slow-moving vessels rarely caused a reaction. It is difficult to elucidate what is causing behavioural responses in these studies as the behaviour of the vessel itself could have a huge impact (Williams et al., 2002).

Effects on acoustic communication have also been noted for a number of species in response to vessel noise (Buckstaff, 2004; Vasconcelos et al., 2007; Holt et al., 2008; Jensen et al., 2009). As ambient noise levels increase, the ability to detect a biologically important sound decreases. The point at which a sound is no longer detectable over ambient noise is known as acoustic masking. The range at which an animal is able to detect these signals reduces with increasing levels of ambient noise (Richardson et al., 1995). A reduction of 26% in the communication range of bottlenose dolphins was estimated within a 50-m radius of small vessels (Jensen et al., 2009). Vasconcelos et al. (2007) also documented that ship noise decreased the ability of the Lusitanian toadfish (*Halobatrachus didactylus*) to detect conspecific acoustic signals. Similarly, studies have demonstrated that boat engine noise significantly elevated the auditory thresholds in a number of fish species, causing significant changes in hearing capability (Scholik and Yan, 2002; Codarin et al., 2009). Possible compensation mechanisms for acoustic masking have been reported, including changes in vocal rate, observed in the bottlenose dolphin, blue whale and brown meagre (*Sciaena umbra*) (Buckstaff, 2004; Melcon et al., 2012; Picciulin et al., 2012). Holt et al. (2008) described an increase in call amplitude of 1 dB for every 1 dB increase in background noise in the killer whale.

Physiological impacts have also been described in fish exposed to boat noise. Hastings et al. (1996) reported damage in the hair cells of the inner ear in teleost fish stimulated with 300-Hz continuous tones at 180 dB re 1 μ Pa 4 days post-exposure. André et al. (2011) noted physiological impairments to cephalopods exposed to relatively low noise levels of short exposure and speculated that the effects of similar noise sources, including shipping, in natural conditions over longer time periods may be considerable.

The west coast of Ireland has probably some of the less polluted regional seas in Europe and could provide a baseline for ambient noise levels to act as reference values to sites elsewhere and for long-term monitoring. Vessel traffic is not uniformly distributed. Main shipping lanes operate on particular routes and tend to minimise the distance travelled. The mapping of vessel density allows Member States to outline areas of high noise pressure to aid in the decision for location of long-term monitoring stations and to be used in conjunction with direct measurements in analysis of annual trends in ambient noise. Additionally, mapping vessel density can determine spatial overlaps with species of concern, i.e. baleen whales. Cetacean sightings data used in the current project will be used to continue assessing spatial overlaps in distribution of low, mid and high-frequency cetacean groups with areas of greatest shipping pressure. Masking is a key concern under Indicator 11.2.1 (low-frequency continuous noise) and highlighting areas of concern is the first step towards successful mitigation.

4.1.1 Objectives

The primary objective addressed in this section was devised to assess and quantify the level of vessel activity at specific geographic locations within Irish waters in an attempt to assess the pressure of continuous low-frequency sounds across the Irish EEZ that will facilitate the Irish Government in fulfilling Ireland's requirements under the MSFD.

- Spatial mapping of vessel density in the Irish EEZ using AIS and VMS data.

Additionally, the work presented here will feed into the objectives designed to create a conceptual framework

and protocol of best practice exploring the locations of monitoring stations in 'noisy' or 'quiet' areas.

- Present a conceptual framework for a network of ambient noise monitoring sites within the Irish EEZ.
- Explore monitoring strategies and assess potential technical solutions for a cost-effective noise monitoring programme in Irish waters.

4.2 Methods

The National Research Council (NRC) suggests that in order to assess vessel density it is important to identify the contributions of vessel types over different temporal and spatial scales (NRC, 2003). AIS and VMS transponders transmit very high frequency (VHF) radio signals containing ship information, including position, heading, course over ground, speed over ground, ship name, type, length overall, draft, destination and a unique Maritime Mobile Service Identity (MMSI) number. These signals are transmitted approximately every 2 h for VMS and every few minutes for AIS. Under EU legislation, VMS transponders are a requirement for all fishing vessels exceeding 15 m in length. In 2000, the International Maritime Organisation (IMO) adopted a new regulation on AIS transponders, which are now a requirement on all passenger vessels regardless of size, all vessels over 300 gross tonnage on international voyages and on all vessels over 500 gross tonnage not engaged in international voyages. Details of vessel activity within the Irish EEZ were acquired through AIS and VMS transponders. Data were sought from the Irish Naval Service, which is responsible for collecting VMS data in Irish waters, and from the Department of Transport, Tourism and Sport for Ireland, which collects AIS data. VMS data were obtained for 2010, 2011 and 2012 and AIS data were obtained for 2010 and 2011.

The specialised package, VMStools, for use under the R statistical software program was used to format both the AIS and VMS data. Inaccuracies were highlighted, including points on land, points recorded with implausible co-ordinates (i.e. latitudes greater than 90° and longitudes greater than 180°) and duplicates (records with the same co-ordinates and date-time stamps) were removed. Additionally, points in

harbours were removed as it was decided that the majority of these vessels would be stationary and therefore would not be an influence on noise levels. Formatted data were then mapped using ArcGIS mapping software (Version 9.3) as the total number of poll events across 50-km² grids; this is the scale currently used in reporting under the Habitats Directive and was deemed a suitable scale for this analysis.

Masking is a key concern under Indicator 11.2.1 (low-frequency continuous noise) and highlighting areas of concern is the first step towards successful mitigation. Cetacean sightings data (Wall et al., 2013) used in [Chapter 3](#) were also used to continue assessing spatial overlaps in the distribution of low, mid and high-frequency cetacean groups with areas of greatest shipping pressure. For details of the functional hearing group methodology, refer to [Chapter 3](#).

4.3 Results

The AIS data acquisition system was intermittently inactive for 192 days in 2010 (53% of the year) and 241 days in 2011 (66% of the year) due to power failures and hardware malfunctions. The VMS data acquisition system was fully functional throughout 2010, 2011 and 2012 and there were no reports of inactivity. Visual cetacean sightings containing species identification, latitude, longitude, date and time obtained from the IWDG (Wall et al., 2013) as part of the seismic survey analysis were mapped to determine any areas of spatial overlap between cetacean distribution and high vessel density. The data provided by the IWDG form the most comprehensive data set on the offshore distribution of cetaceans and are invaluable in assessing these spatial overlaps.

4.3.1 VMS density

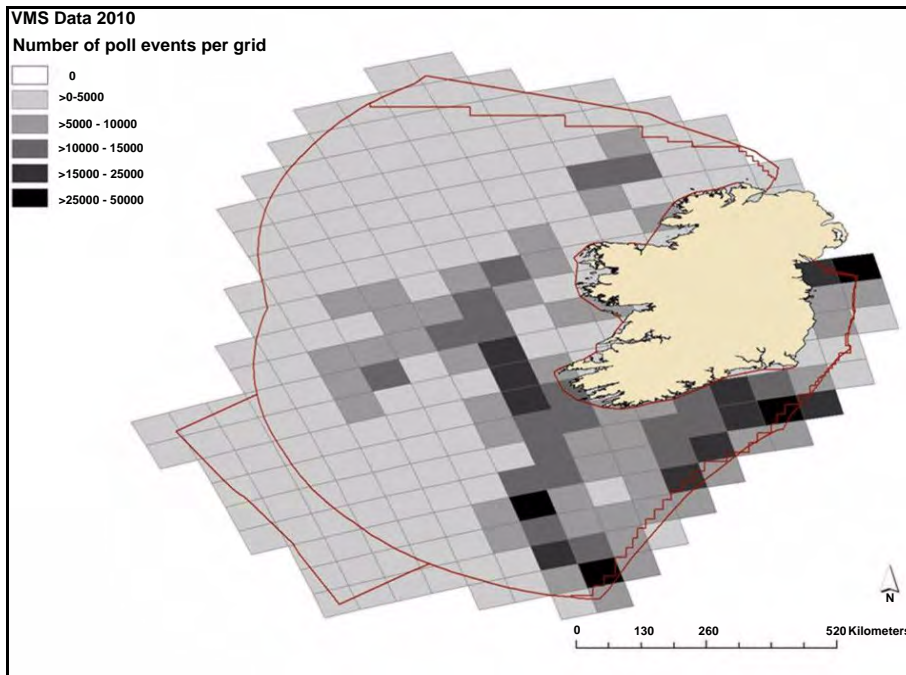


Figure 4.1. Vessel density, within the Irish Exclusive Economic Zone for 2010, using Vessel Monitoring System (VMS) data. Density is shown in a graduated colour scheme, with darker colours representing the densities. The MSFD Boundary is shown in red; this is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

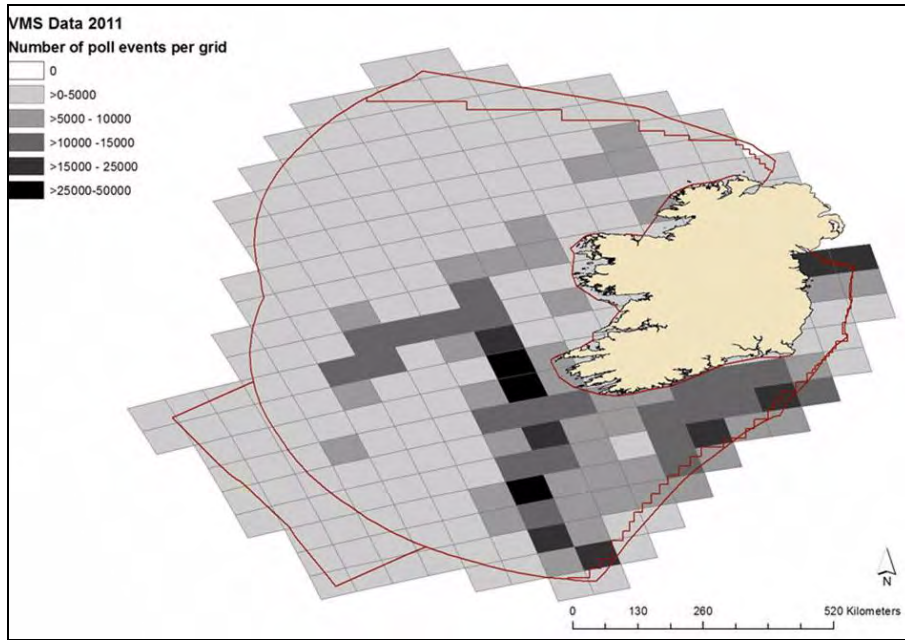


Figure 4.2. Vessel density, within the Irish Exclusive Economic Zone for 2011, using Vessel Monitoring System (VMS) data. Density is shown in a graduated colour scheme, with darker colours representing the densities. The MSFD Boundary is shown in red; this is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

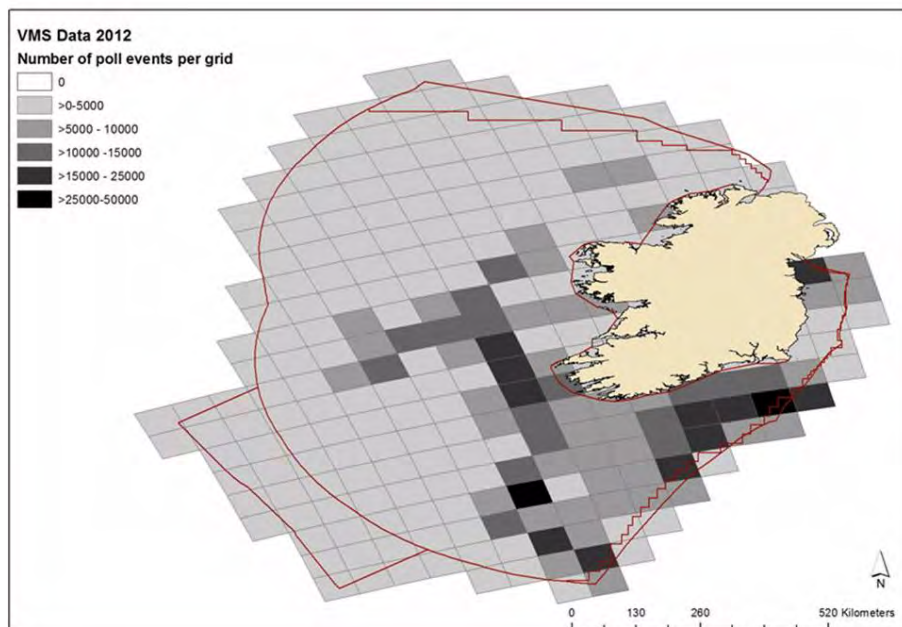


Figure 4.3. Vessel density, within the Irish Exclusive Economic Zone for 2012, using Vessel Monitoring System (VMS) data. Density is shown in a graduated colour scheme, with darker colours representing the densities. The MSFD Boundary is shown in red; this is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

4.3.2 VMS density and cetacean overlay

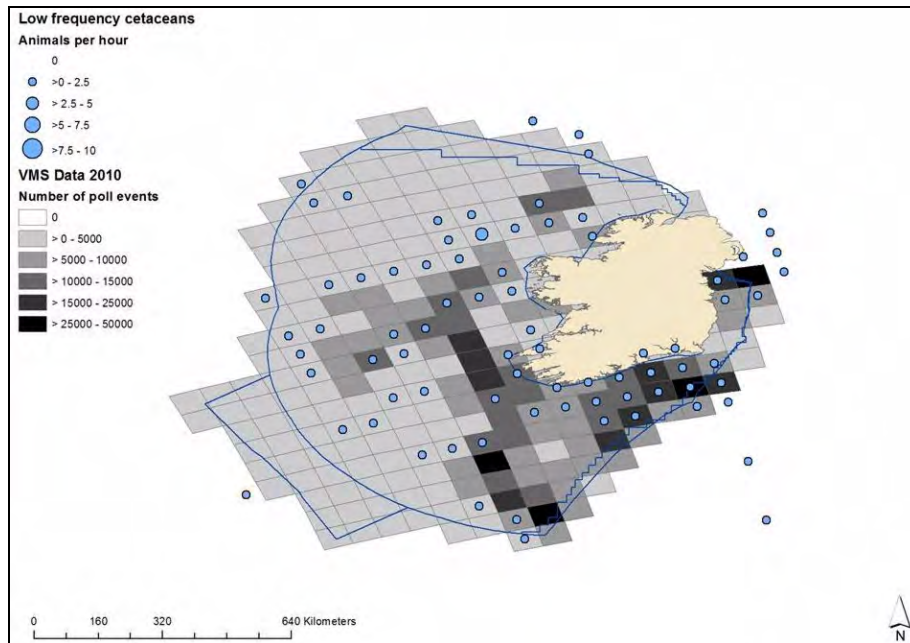


Figure 4.4. 2010 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of low-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

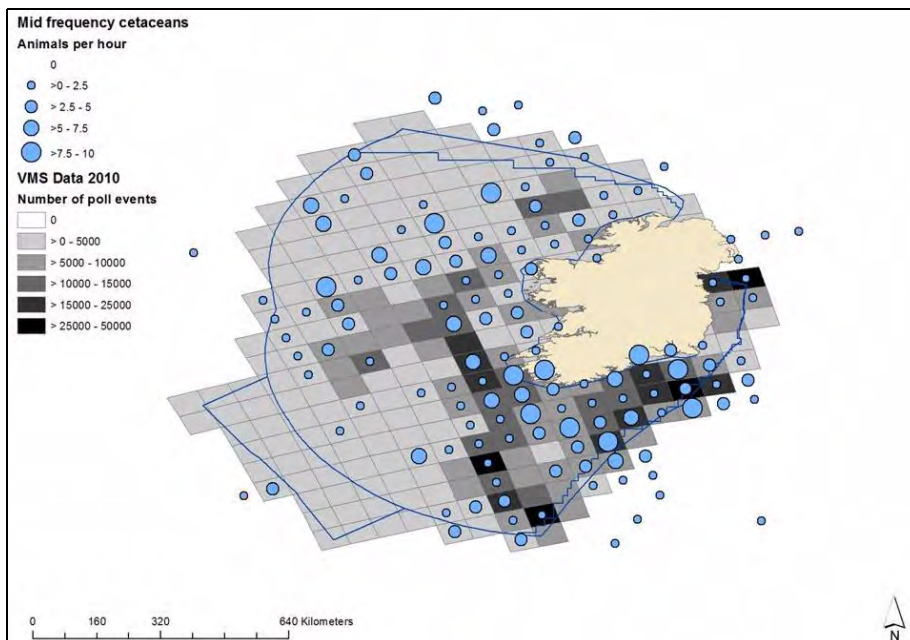


Figure 4.5. 2010 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of mid-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

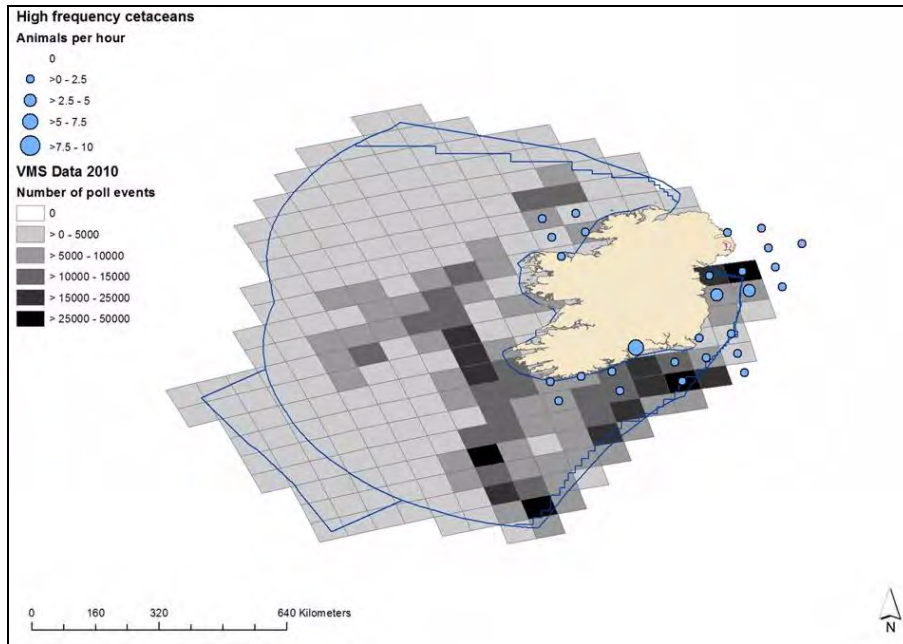


Figure 4.6. 2010 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of high-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

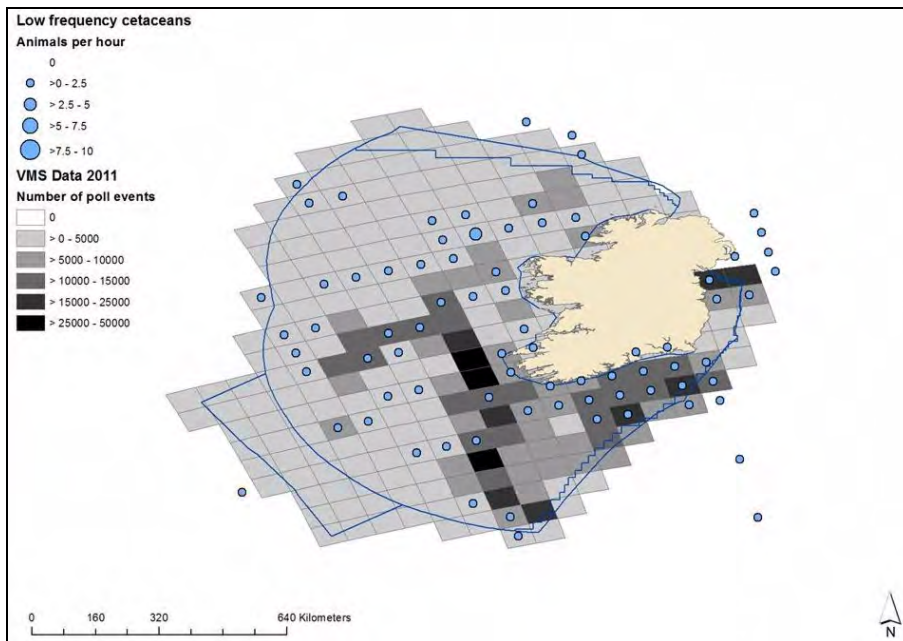


Figure 4.7. 2011 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of low-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

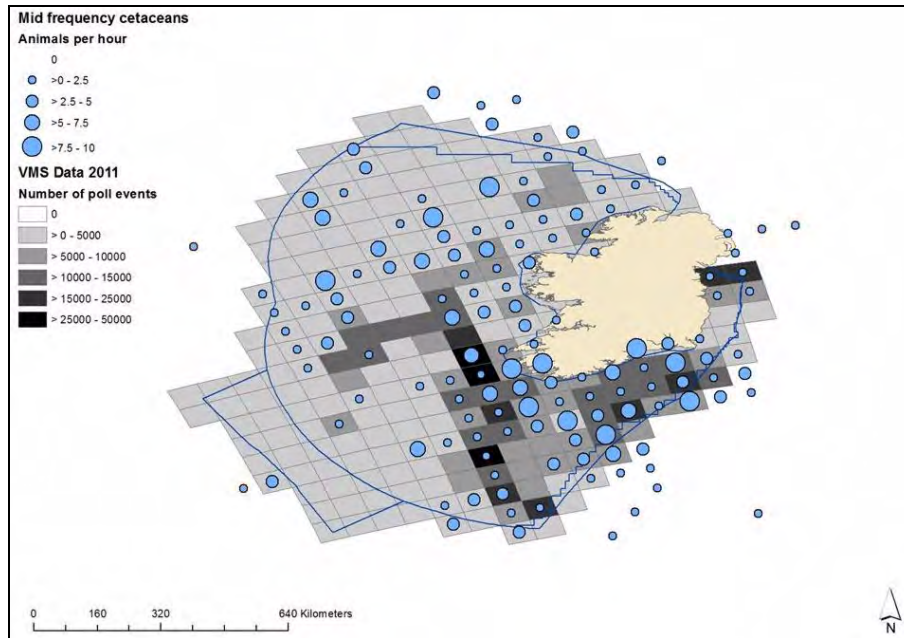


Figure 4.8. 2011 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of mid-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

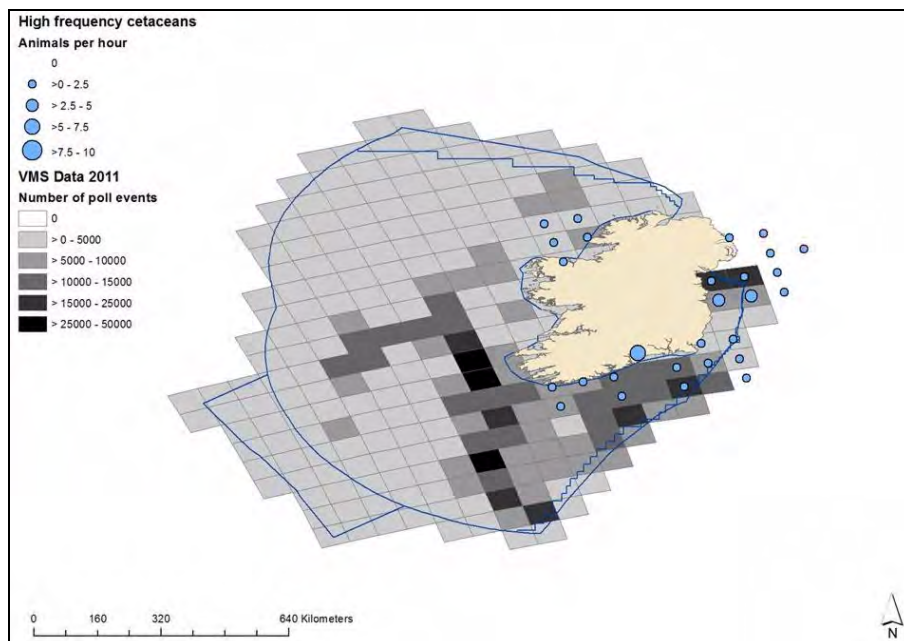


Figure 4.9. 2011 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of high-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

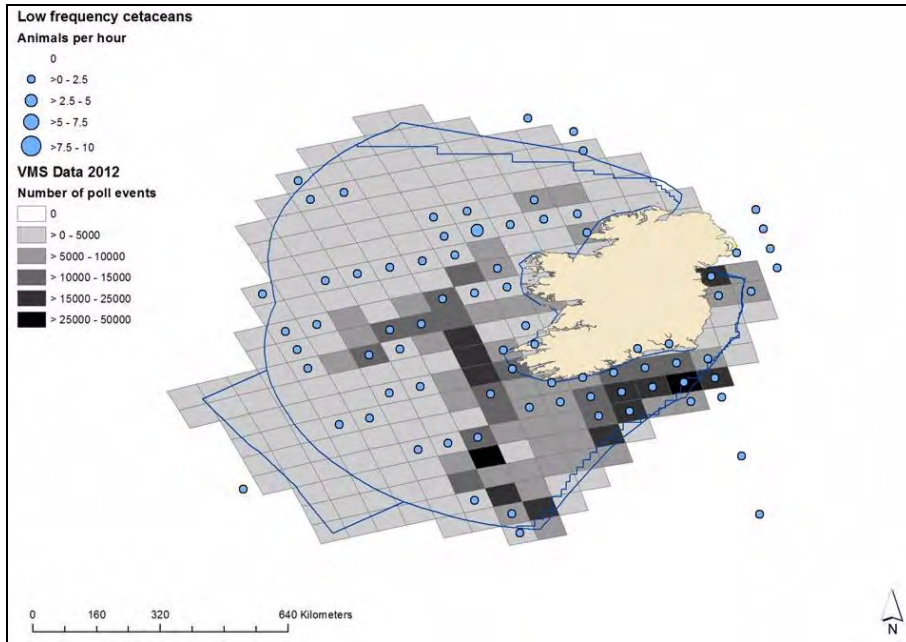


Figure 4.10. 2012 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of low-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

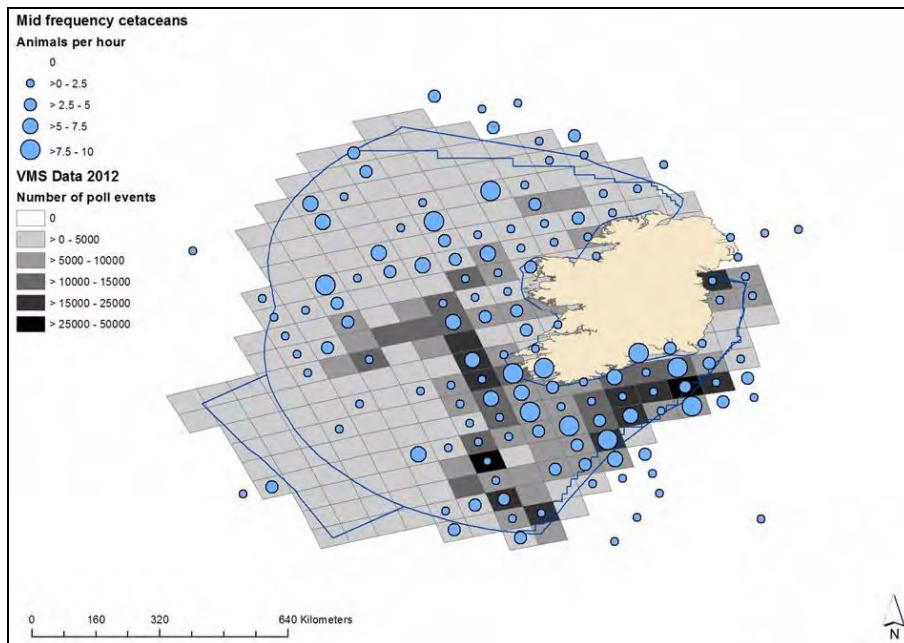


Figure 4.11. 2012 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of mid-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

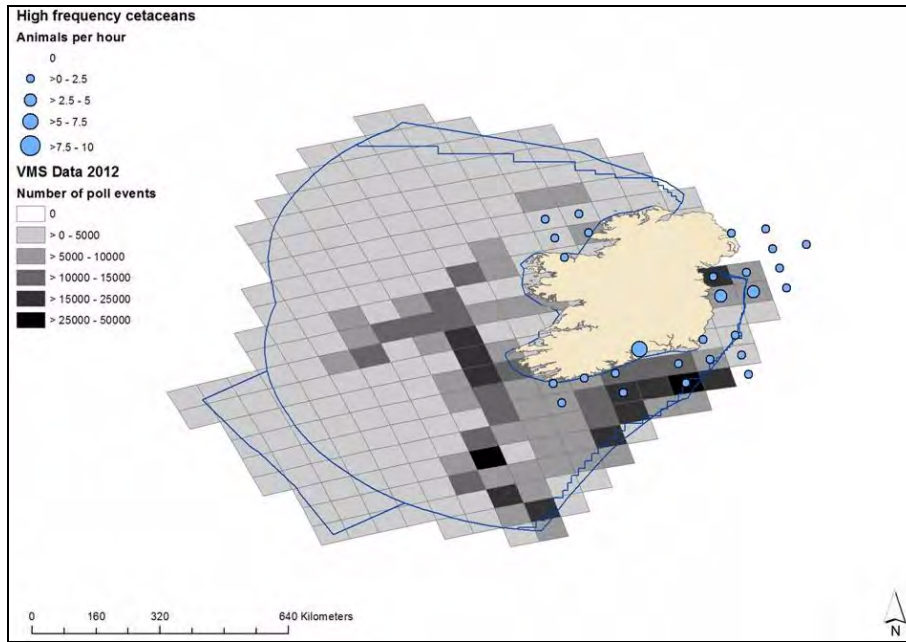


Figure 4.12. 2012 Vessel Monitoring System (VMS) data and cetacean relative abundance, number of high-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

4.3.3 AIS density

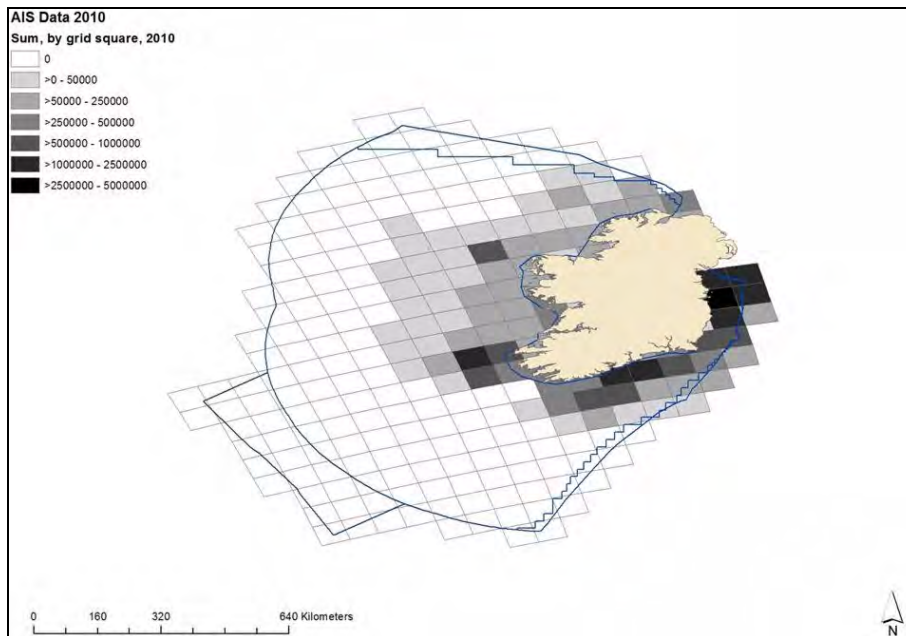


Figure 4.13. Vessel density, within the Irish Exclusive Economic Zone for 2010, using Automatic Information System (AIS) data. Density is shown in a graduated colour scheme, with darker colours representing the densities. The MSFD Boundary is shown in blue; this is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

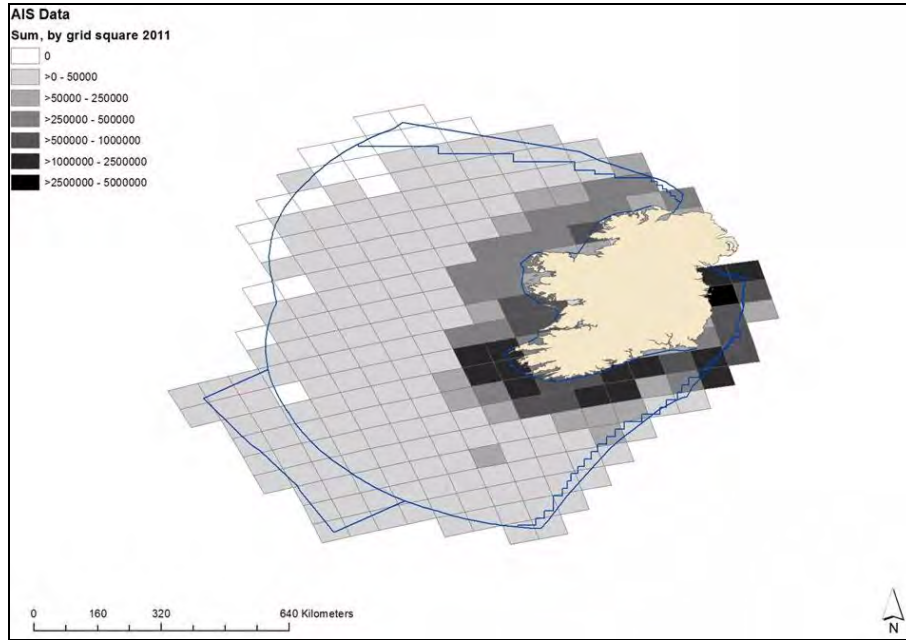


Figure 4.14. Vessel density, within the Irish Exclusive Economic Zone for 2011, using Automatic Identification System (AIS) data. Density is shown in a graduated colour scheme, with darker colours representing the densities. The MSFD Boundary is shown in blue; this is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

4.3.4 AIS density and cetacean overlay

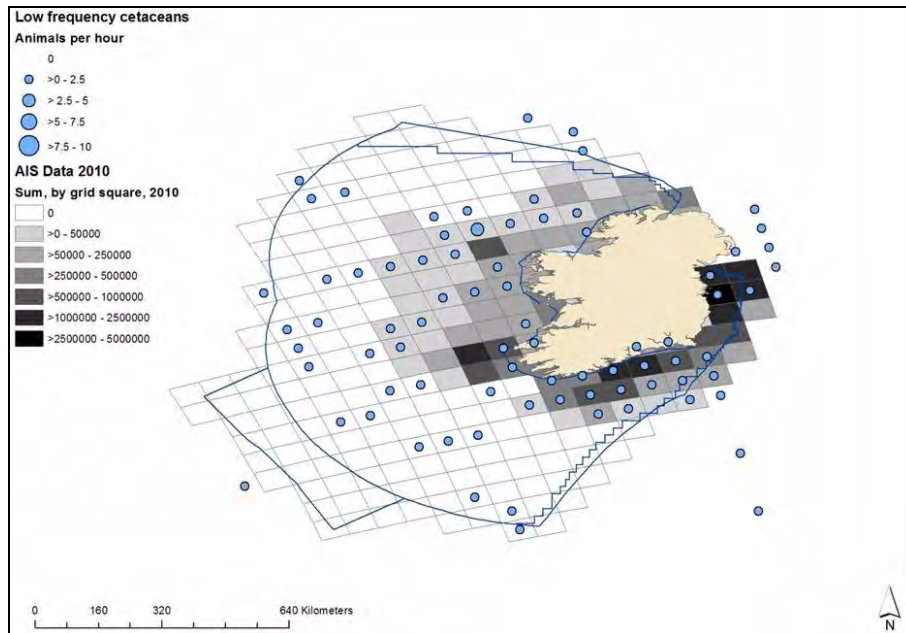


Figure 4.15. 2010 Automatic Identification System (AIS) data and cetacean relative abundance, number of low-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

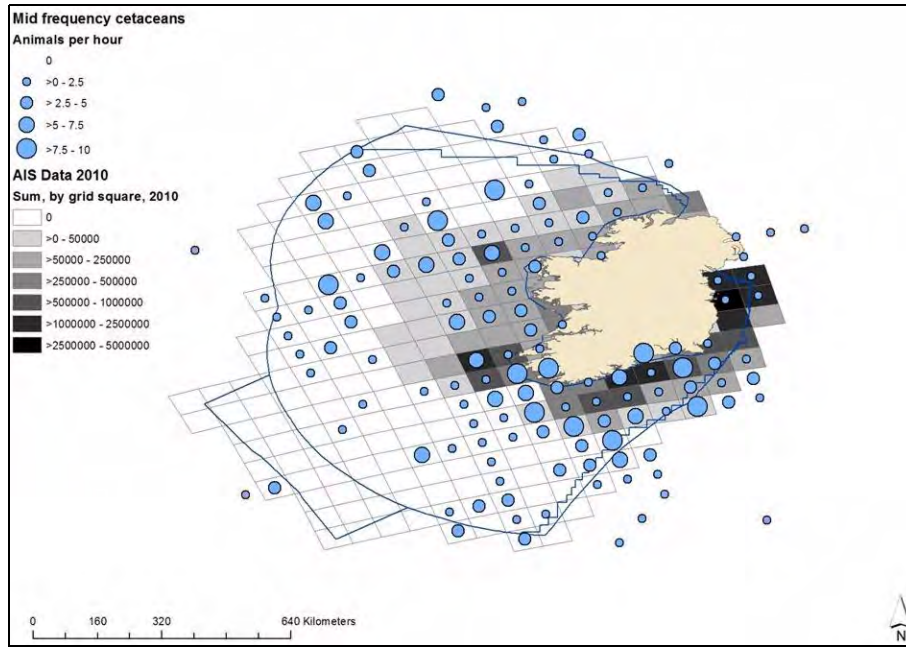


Figure 4.16. 2010 Automatic Identification System (AIS) data and cetacean relative abundance, number of mid-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

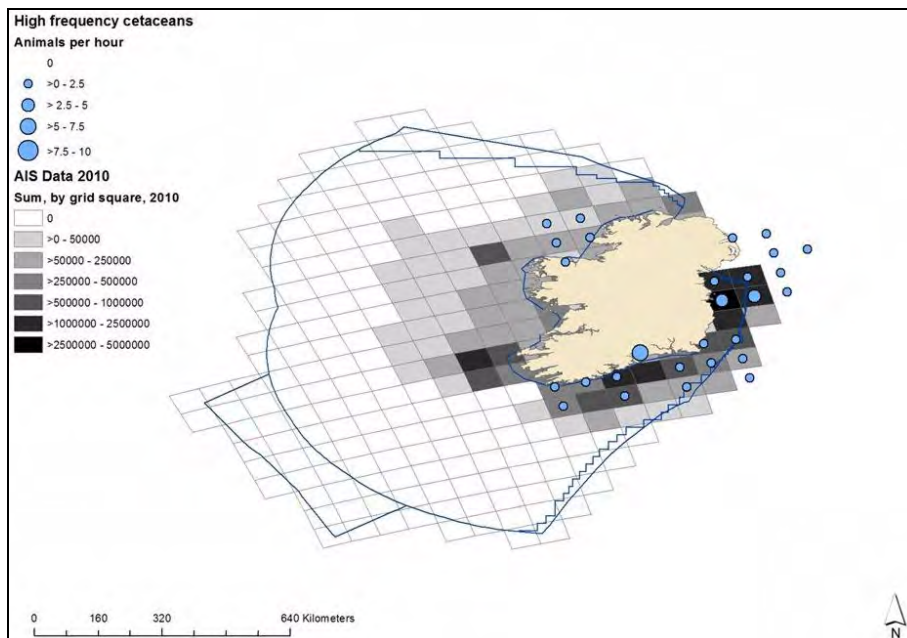


Figure 4.17. 2010 Automatic Identification System (AIS) data and cetacean relative abundance, number of high-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

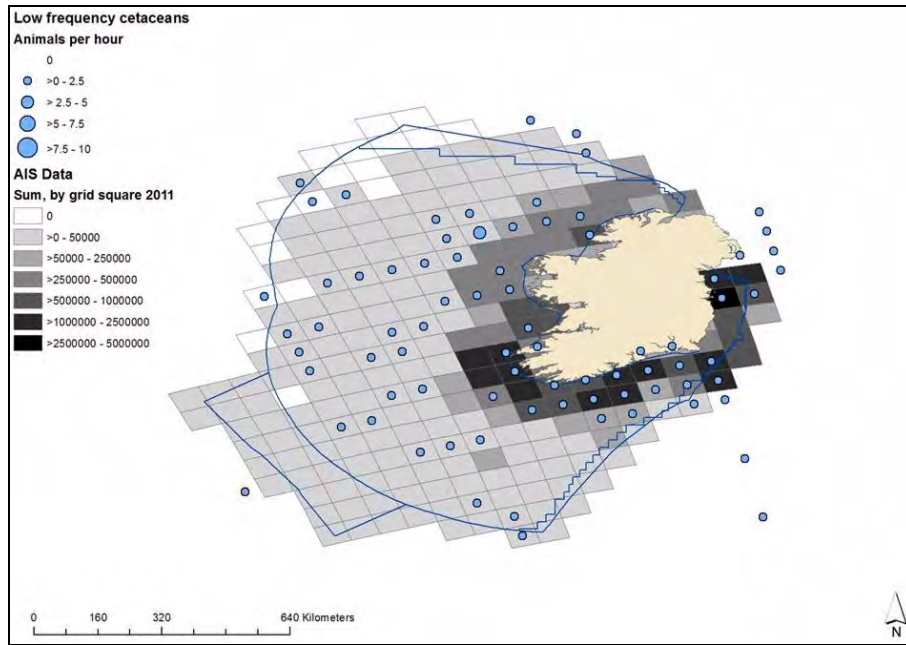


Figure 4.18. 2011 Automatic Identification System (AIS) data and cetacean relative abundance, number of low-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

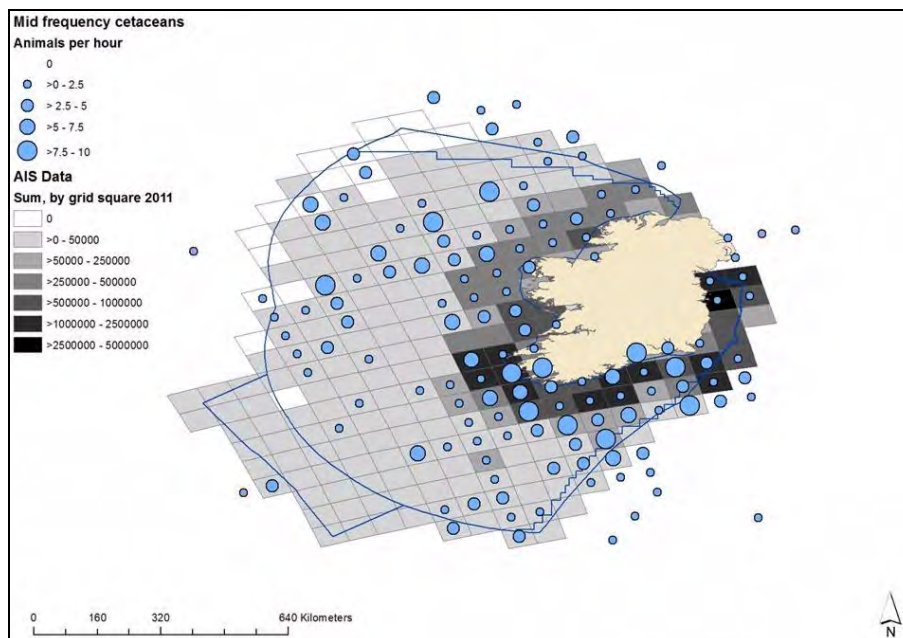


Figure 4.19. 2011 Automatic Identification System (AIS) data and cetacean relative abundance, number of mid-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

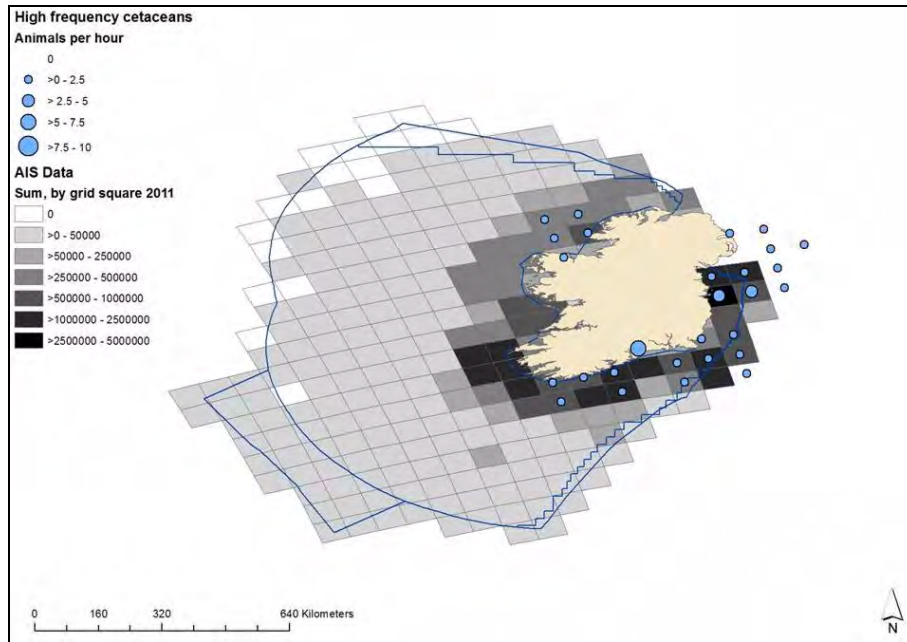


Figure 4.20. 2011 Automatic Identification System (AIS) data and cetacean relative abundance, number of high-frequency cetaceans recorded per survey hour (from Wall et al., 2013) shown in circular graduated symbols. The 200 nautical mile limit shown in blue is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

4.4 Discussion

AIS data are a useful tool for quantifying the densities of vessel traffic, thus allowing Member States to highlight ‘noisy’ areas that may warrant further monitoring under the MSFD. Small recreational vessels and fishing vessels are also common in Irish waters but are not required to use AIS. The inclusion of VMS data aims to reduce this limitation; however, the analysis presented here does not include density from vessels without AIS or VMS transponders, and this is a notable limitation if relying on these data sets as the sole source of vessel traffic data. Vessel density analyses in the Irish EEZ have highlighted a number of areas that are subject to higher densities of vessel traffic. AIS data analysis highlighted the east and south coasts as high density areas; a proportion of this is likely to be attributed to passenger ferries operating routes between Ireland and the UK and mainland Europe. VMS data analysis highlighted areas along the south coast of Ireland and areas further offshore south and south-west within Ireland’s EEZ subject to high fishing vessel densities. These areas were continually highlighted throughout 2010, 2011 and 2012.

Results of vessel density analysis in the Irish EEZ highlight a number of spatial overlaps with areas of cetacean presence. As with the seismic survey pressure, particular concern is in overlap with the low-frequency cetaceans as the auditory bandwidth of these species overlaps with the frequencies associated with shipping. Low-frequency cetaceans occurred along the south and south-west coasts of Ireland; re-sightings of fin whales have been reported in coastal waters of the Celtic Sea (Whooley et al., 2011). These occurrences overlap with areas with high vessel densities from both VMS and AIS data. Low-frequency cetaceans were also prevalent along the north-west continental shelf slope areas and slopes of the Porcupine Bank concurrent with high VMS densities. The diet of fin and humpback whales in the Celtic Sea has been reported to comprise largely of herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and krill (*Meganyctiphanes norvegica* and *Nyctiphanes couchii*), noting that Age 0 sprat and herring comprise a large proportion of the diet in both species, followed by older sprat (Age 1–2) and older herring (Age 2–4) (Ryan et al., 2013). It is likely that the fishing vessels and the low-frequency cetaceans are utilising the

same natural resource in these areas of spatial overlap.

The acoustic signature of a vessel depends on a number of characteristics, including gross tonnage, draft, operating equipment, speed and sea state (Ross, 1976; McKenna et al., 2012; OSPAR, 2012). The primary source of noise emissions from commercial vessels is due to propeller cavitation (Hildebrand, 2005). A study conducted in the English Channel and in the Minch, Scotland, reported significantly greater noise emissions from vessels exceeding 150 m (OSPAR, 2012). Small ships tend to be quieter at low frequencies but can approach or exceed noise levels of larger ships at higher frequencies (Hildebrand, 2005). Source levels for vessels, referenced to dB re 1 μ Pa at 1 m, range from 140 dB for small fishing vessels to 195 dB for super tankers (Hildebrand, 2005). Given this information, in order to further develop the analysis of vessel density in Irish waters, it is recommended that vessels are further divided into categories similar to those of Bassett et al. (2012). As the data contain sensitive information with regards to vessel identity, that information is removed before access is granted; it

may be possible to divide vessels based on length or gross tonnage.

4.5 Recommendations

There were a number of limitations to this assessment and as a result the following recommendations have been proposed:

- The VMS and AIS analyses can be repeated for subsequent years to give an indication of the annual trend in vessel densities in Irish waters.
- Future assessment could look into the use of vessel categories based on gross tonnage or activity type. This would allow a more detailed analysis of the main contributors to vessel noise in Irish waters.
- Attempts should be made to continue contact with the Irish Naval Service and the Department of Transport, Tourism and Sport regarding their VMS and AIS data.
- Smaller pleasure crafts should be encouraged to use AIS transmitters.

5 Analysis of Indicator 11.2.1 Low Frequency Continuous Noise

5.1 Introduction

This chapter has been completed through external assistance from the Technical University of Catalonia (UPC) Laboratory of Applied Bioacoustics (LAB), Spain, and Biospheric Engineering Ltd, Galway, Ireland. Full reports provided by the UPC LAB and Biospheric Engineering Ltd can be found in the supporting documents (André and van der Scharr, 2013; McKeown, 2013).

5.1.1 Objectives

A long-term deployment was designed to obtain a data set for analysis and test the efficacy of the equipment provided by the UPC LAB in Irish waters (LIDO (Listen to the Deep Ocean Environment) equipment). Additionally, a number of short-term (15-min files) recordings were carried out at a number of sites in busy ports and harbours using a system developed by Biospheric Engineering. The following objective is addressed in this chapter:

- To deploy acoustic monitoring equipment and assess noise levels and to evaluate the use of this technique as a means for Ireland meeting requirements under the MSFD.

The objective sought to gain knowledge and experience of recording ocean noise, as well as to facilitate recommendations for future studies, and to design a framework for a network of noise monitoring stations to ensure that Ireland achieves and maintains GES under the MSFD.

5.2 UPC LAB

An SMID digital hydrophone installed at the Tarbert Jetty, Co. Kerry ([Fig. 5.1](#)), in the Shannon Estuary cSAC was connected to an embedded single board computer (SBC) device that conducted noise measurement in the third octave bands centred at 63 and 125 Hz as required under the MSFD Indicator 11.2.1 of Descriptor 11; short tonal signals between 2,500 and 20,000 Hz and impulsive signals between 20, 46 and 94 kHz were also monitored for dolphin sonar. A real-time data stream was available for the general public at www.listentothedeep.com. An AIS receiver was also installed at the Jetty which was connected to ShipPlotter software (www.shipplotter.com). The noise measurements and public data streams and the AIS data were transferred to the UPC LAB database server in Vilanova i la Geltru (Spain) over a 3G network connection.

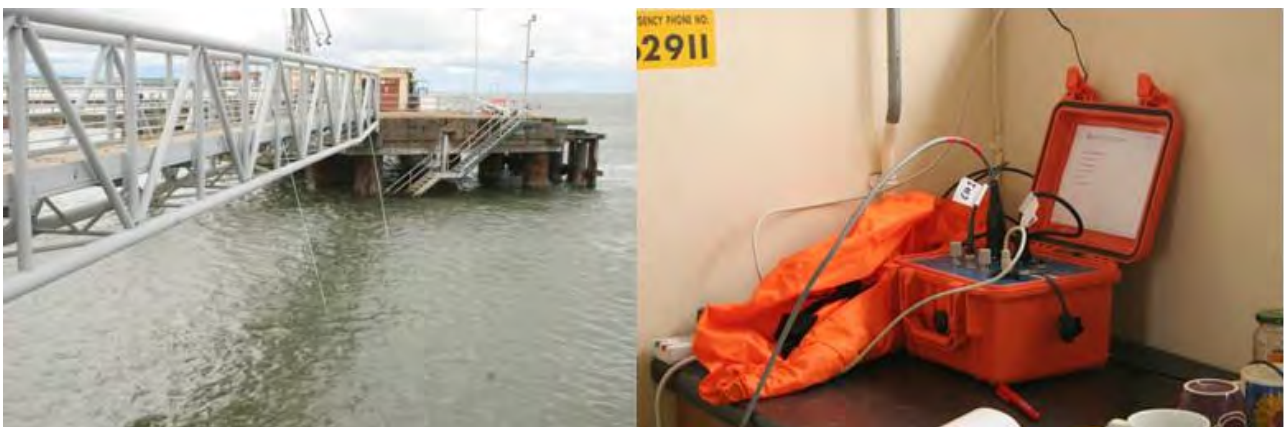


Figure 5.1. Installation of hydrophone and electronics box at Tarbert Jetty.

A real-time data stream was available for the general public at www.listentothedeep.com. All analysis results were made privately available to the GMIT at <http://www.listentothedeep.net/shannon> and can be made publicly available if required.

5.2.1 Noise measurements

The deployment location of the LIDO equipment was positioned in a strong tide and it is suspected that part of the installation moved or vibrated during peak currents producing a ‘banging’ noise, in addition to the low-frequency noise that can be expected when water flows along the hydrophone. The system was powered with mains current and, although grounded, showed some noise typical for 50 Hz alternate power. This may have been caused by the nearby power plant and associated cables. The 63 Hz third octave band measurement has been affected by this; the 125 Hz third octave band had minimal influence from these power lines (Fig. 5.2).

5.2.2 Shipping activity

To analyse the shipping activity on weekdays, histograms were made averaging the number of received AIS messages over each hour of the day during September 2012. Only movements with a speed over 1 knot were taken into consideration. The ferry activity is shown in Fig. 5.3. On average, about four ships seem to pass Tarbert per day. The shipping

activity appears to be concentrated mostly in mornings and evenings, with especially high activity from Thursday night to Friday morning.

5.2.3 Channel characterisation

The Shannon Estuary has a very complicated geometry and bathymetry. An attempt was made to characterise the transmission loss in the channel using the received level measurements from ships passing the hydrophone in combination with their positions taken from AIS data. Noise levels received at the hydrophone during ferry operations are shown against the distance of the ferry to the hydrophone in Fig. 5.4. The measurements are given relative to the median noise level measured during September 2012. Wide dispersion around the median is likely to be due to contributing noise sources (e.g. self-noise) and directivity of the source level at the ferry.

5.2.4 Sound pressure level (SPL) estimation

A ferry track consisting of 13 points was computed averaging over all available tracks in September. An omnidirectional source level was taken from literature. McKenna et al. (2012) lists source levels for vehicle carriers of lengths between 173 and 199 m of around 170 dB re 1 μ Pa at 1 m for the third octave centred on 125 Hz. The ferries operating in the channel are smaller than this and a source level estimate of 160 dB was used. Figure 5.5 shows the ferry track and the

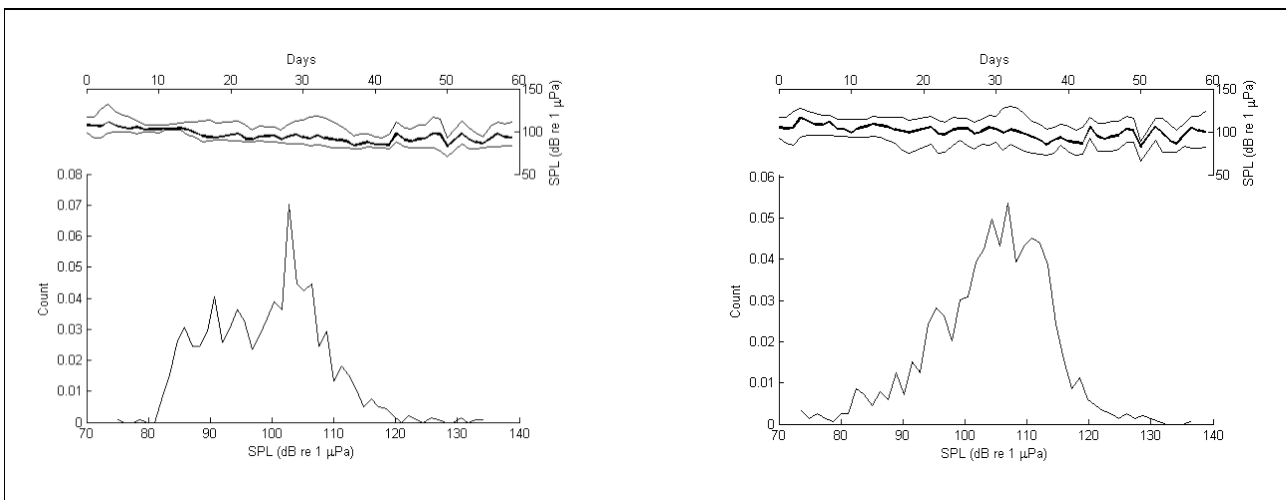


Figure 5.2. Noise levels at 63 (left) and 125 (right) Hz. The lower halves of the images show the distribution, upper halves the 5th, 50th and 95th percentiles. The wide range of measured levels are likely caused by the self-noise. SPL, sound pressure level.

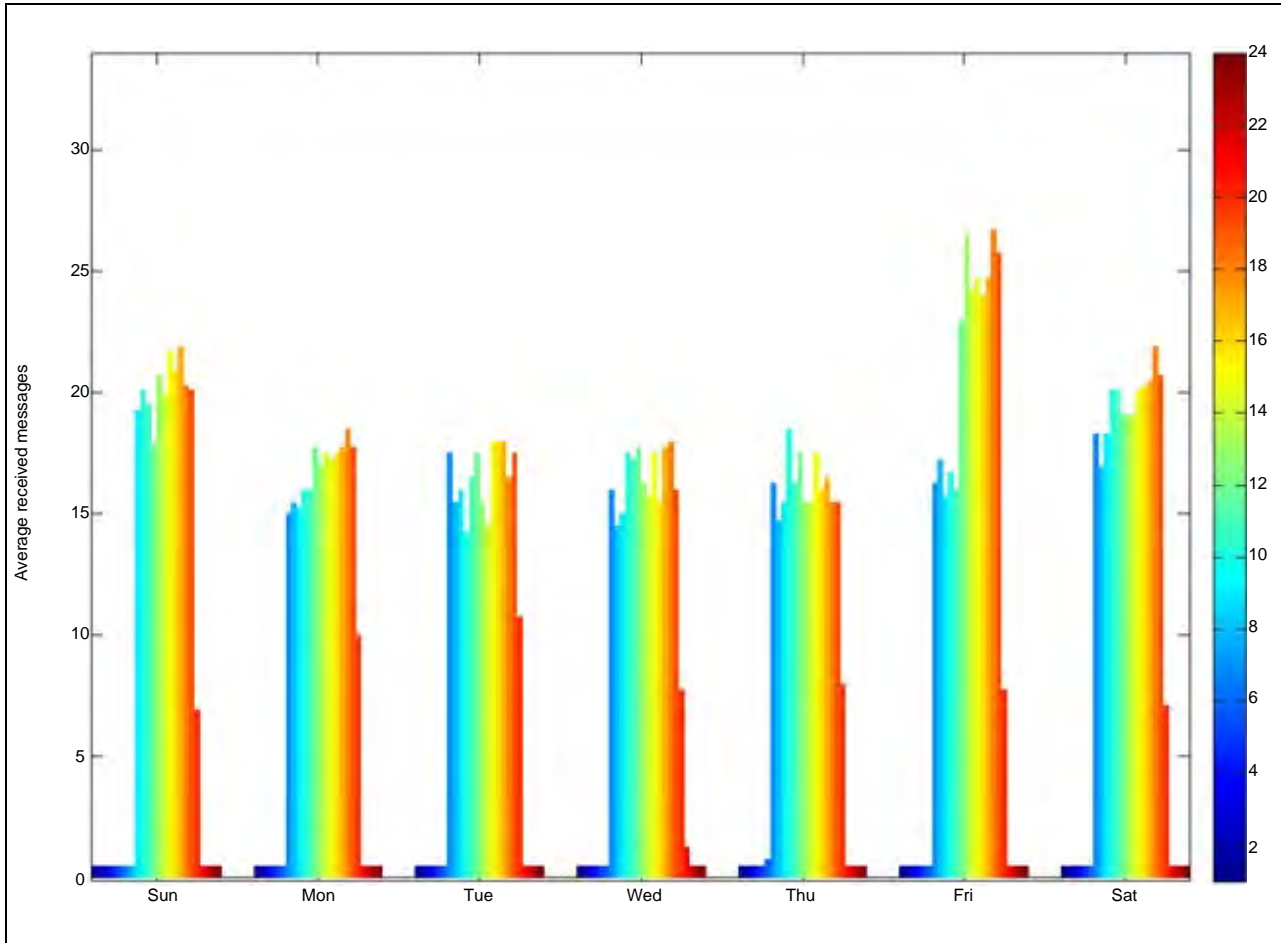


Figure 5.3. Hourly ferry activity based on received Automatic Identification System (AIS) messages during weekdays in September 2012 at Tarbert Jetty, Co. Kerry, Ireland.

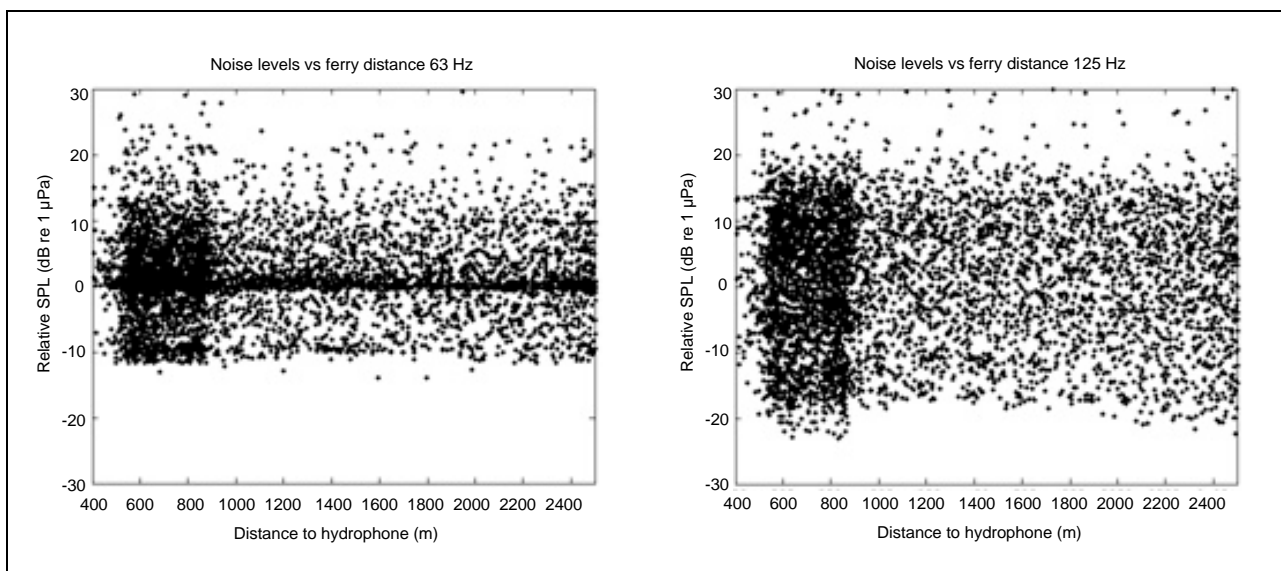


Figure 5.4. Received levels versus distance to hydrophone during ferry operations.

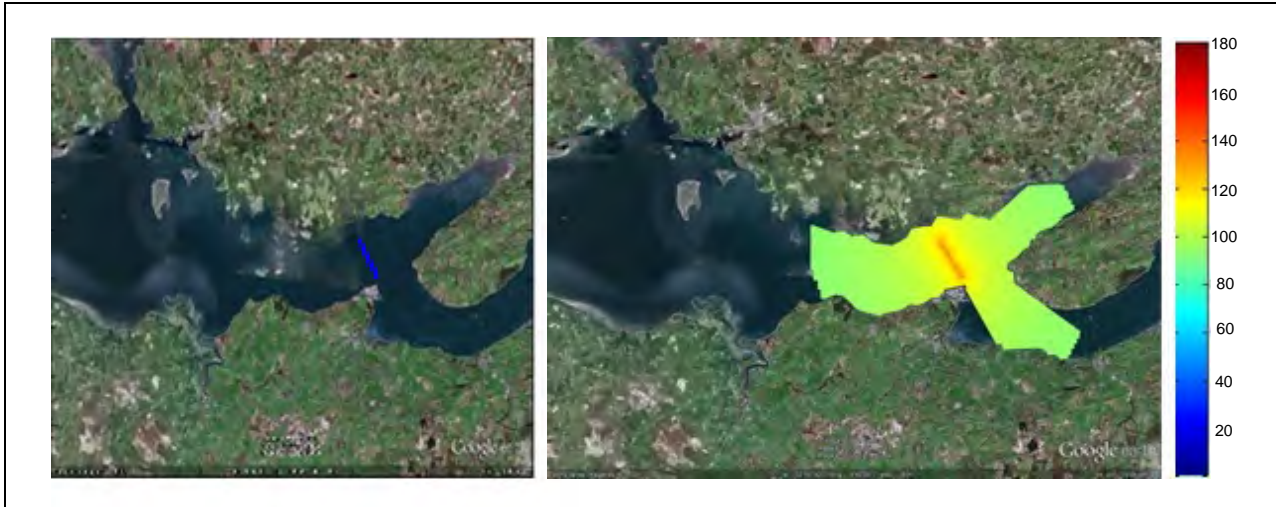


Figure 5.5. Estimated sound pressure level during ferry activities.

estimated received SPL of points around the track of the ferry based on their proximity to the track and a transmission loss of $18 \log(R)$. From the model, it is expected that the ferry levels should have been measured more clearly. Very likely the source level estimation is too high.

5.2.5 Sound exposure level (SEL) estimation

For completeness, SEL estimations were made for the 125 Hz third octave band and over one day based on ferry and other shipping traffic. This is presented as an example that should be improved upon when more information becomes available on the transmission loss in the channel and more precise source level estimates can be measured. The SEL for the ferry was

based on summing the received level estimates over all 13 positions of the track, maintaining each position for 45 s. This assumes that a ferry crosses the main part of the channel in about 10 min; the ferry timetable mentions a travel time of 20 min, but this is understood to include manoeuvring at ports. A total of 24 ferry passages were taken into account based on the weekday ferry timetable. The result is shown in the left image in Fig. 5.6. For other shipping traffic, a passage time of 30 min was assumed based on AIS information. Spreading this equally over the 65 data points led to maintaining a ship for 27 s at each position. It was assumed that four ships pass Tarbert per day. The daily SEL estimate for this traffic is given in the right image in Fig. 5.6.

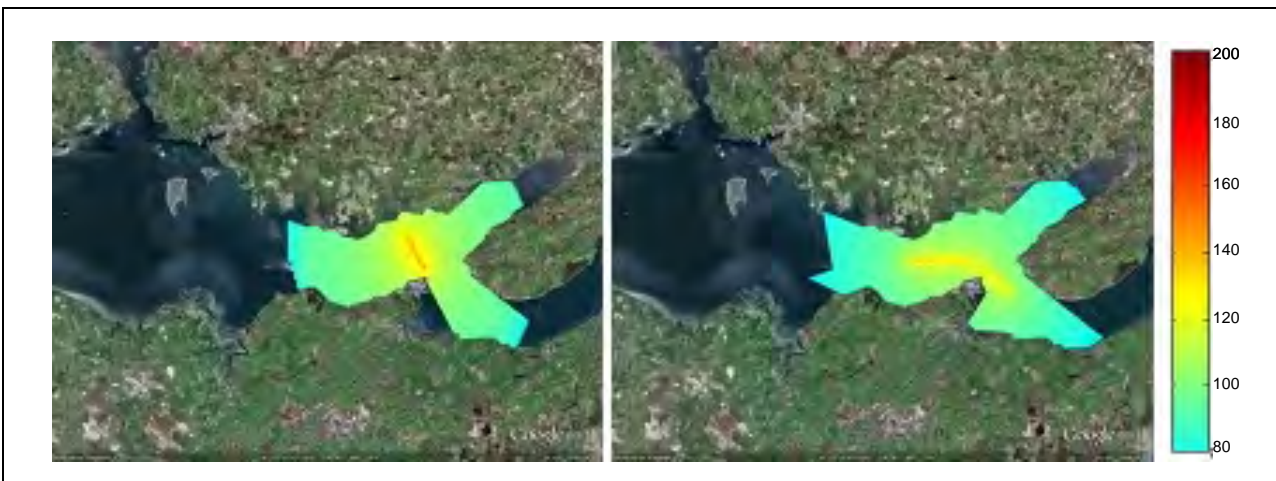


Figure 5.6. Estimated sound exposure level over 1 day due to ferry and other shipping activities.

5.3 Biospheric Engineering Ltd

5.3.1 Equipment set-up and deployment

The monitoring equipment used in this project was developed by Biospheric Engineering Ltd as part of an ongoing research and development programme on underwater noise measurement. Calibrations were carried out at 250.12 Hz, 500 Hz, 1 kHz, 5 kHz, 10 kHz and 20 kHz using a Bruel and Kjaer type 4223 hydrophone calibrator and cross-checked with a Bruel and Kjaer type 2250 sound-level analyser before and after each set of measurements.

Three locations were chosen: Dublin Bay, the Shannon Estuary and Galway Bay. At each location, one measurement was to be taken in a 'noisy' setting and one in a 'quiet' one. Due to the shallow water depths in Dublin and Galway, it was decided to locate the noise monitoring equipment on the 10 m contour line. In the Shannon Estuary, it was possible to locate the recorder on the 20-m contour line (preliminary recordings at the 10-m contour in the Lower Shannon Estuary could not be used due to extensive biological noise). Placing the recorder in similar depths at each location was to ensure that the measurement sites were as similar as possible. Weather conditions at each location were also matched by having fair weather with winds of less than 10 knots at each location for the duration of measurement. Deployment at each location comprised the recording device in a protective cage (converted lobster pot). Data were in the form of 15-min-long WAV files, providing a continuous audible record of the noise events. Each file was first analysed to determine the RMS noise level every 125 ms. This resulted in 7,200 RMS values for each file. These RMS values were analysed in turn to determine the percentile values so that background levels could be isolated from events such as shipping noise.

5.3.2 Signal analysis

Post-analysis was carried out using Avisoft Bioacoustics SASLab Pro and Signal Lab's SigView 32 software packages. It is clear that the noise levels can be divided into three typical categories:

1. Background noise level (no dominant sound, low noise level);
2. Biological noise level (louder sounds not

attributable to anthropogenic sources); and

3. Shipping noise (louder sounds attributable to shipping traffic).

Periods where either shipping noise, biological noise or background noise was the dominant noise source were isolated. Each period was then analysed and a third octave spectrum for the three main noise source types prepared. In order to get a greater understanding of the noise level on a longer term, the RMS noise level was plotted for each of the 15-min monitoring periods. Along with the RMS value, instantaneous noise levels were evaluated to calculate percentile noise levels. All results unless otherwise noted are broadband (5 Hz to 20 kHz) RMS values.

At the northern end of Dublin Bay, noise levels were between 125 dB and 135 dB re 1 μ Pa across all frequency bands whereas at the southern site the noise levels were marginally higher, while still remaining below 140 dB re 1 μ Pa. At the northern site, the low-frequency components (below 100 Hz) were about equal for the three noise categories whereas at the southern end the biological and background noise levels do not appear to have these low-level frequency components. There were significant temporal variations, related to shipping activity and what appears to be an elevated noise level during night hours when compared with daytime. Noise levels at Galway were lower than those measured at Dublin Bay. Shipping noise was not as prevalent but a large number of small vessels are evident during the day, resulting in short duration peaks in noise level. Mean noise levels were in the order of 100 dB re 1 μ Pa, with peak levels remaining below 120 dB for a large portion of the day. The Shannon Estuary is a busy shipping area, with both transiting and stationary vessels present at all times. The baseline noise level in the Shannon Estuary was between that measured at Dublin and that measured in Galway ([Table 5.1](#)) The standard deviation is high in Dublin due to the range and frequency of shipping events. In the Shannon Estuary, there was a limited number of shipping transits, resulting in a lower variation, while the level of large ships in the area maintained a constant shipping noise level.

Table 5.1. Mean noise levels in dB re 1 μ Pa for each of the monitoring locations.

Location	Mean noise level (dB re 1 μ Pa)	Standard deviation (dB)
Dublin Bay	113	8.2
Galway Bay	103	4.2
Shannon Estuary	100	7.5

5.4 Recommendations

This report provides initial data on the noise levels likely to be encountered in Irish coastal waters. These deployments, coupled with the LIDO monitoring by the UPC LAB and the Coastal and Marine Research Centre (CMRC – University College Cork, Ireland) with Quiet Oceans (Sutton, 2013), are the first underwater noise measurements in Irish waters to be undertaken in comparable sites with a view to understanding ‘background’ noise levels under the MSFD. The LIDO deployment provided the first real-time monitoring of noise in Irish waters and also had outreach capabilities whereby the general public could access the real-time sound monitoring from the Shannon Estuary. Additionally, the equipment had a cetacean monitoring capability with dolphins recorded at the site although detections were often difficult to extract due to self-noise.

A single measurement point in such a complex environment certainly does not allow characterisation of the entire channel. Multiple measurement points, not necessarily operating in parallel, should be used to estimate the transmission loss at different parts of the channel that can then be used for subsequent SEL estimations. In order to estimate the communication

range of dolphins in the presence of ships, the whole channel would need to be characterised and this was outside the scope of this project.

For future monitoring at the Shannon estuary site under the MSFD, the following recommendations apply:

- Installation of the hydrophone on the estuary floor to avoid movement, or installation on a fixed structure to avoid wear and tear.
- Measurements at multiple points to characterise the channel in greater detail.
- Estimation of source levels of the ferries, which appear to make up most of the shipping traffic.
- A higher mount point for the AIS antenna to improve ship tracking through the estuary and SEL estimation.
- If installation at the jetty is maintained, remote power-up and down of the acquisition system to reduce both necessary assistance at the jetty and the down time of the system.
- These recommendations should be followed for similar deployments at additional sites.

6 Recommendations for Implementation of an Ambient Noise Monitoring Network in Irish Waters

Indicator 11.2.1 is a guideline put forward by the European Commission that must be met by each Member State by the year 2020. The criterion on which this is based is Indicator 11.2.1: Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz, measured by observation stations and/or with the use of models if appropriate. A national strategy for monitoring marine noise should be developed that would collect data on a variety of temporal and spatial scales. This is likely to employ different technologies to broaden spatial coverage and may possibly include cabled applications that give high temporal resolution of marine noise at key locations.

In order to achieve a scientifically sound and cost-effective long-term ambient noise monitoring programme, it is essential to review existing noise monitoring programmes and available equipment. Furthermore, it is necessary to assess strategies and technical solutions for a long-term noise monitoring programme specific to Irish waters, advising on the implementation of such a system for delivery under the MSFD in a protocol of best practice.

This chapter aims to address the following deliverables:

- Present a conceptual framework for a network of ambient noise monitoring sites within the Irish EEZ; and
- Explore monitoring strategies and assess potential technical solutions for a cost-effective noise monitoring programme in Irish waters.

Currently, two companies have deployed long-term noise monitoring equipment in Irish waters for the MSFD requirements: UPC LAB and Quiet Oceans. A detailed outline from the UPC LAB is given in this chapter, including costs for the erection of noise monitoring sites. For details on Quiet Oceans equipment and services, refer to Sutton (2013).

6.1 Existing International Acoustic Monitoring Networks and Technologies

Indicator 11.2.1 makes reference to five different acoustic monitoring networks set up around the world ([Table 6.1](#)), each employing a different monitoring technique. Some use hydrophones that are suspended from a floating buoy or are floating just above the mooring block or anchor. Others are part of an underwater marine observatory (NEPTUNE, Canada; JAMSTEC, Japan). Some of the issues that are being addressed include flow noise, hydrophone cable strum, mechanical noise and hydrostatic pressure fluctuations. These problems are mainly to do with buoyed platforms and can have a dramatic effect on the quality of data logged by the instruments on board.

An appropriately located cabled observatory is an ideal solution for acoustic monitoring, given that there are few power and bandwidth limitations on such an infrastructure. However, the indicative cost of an open ocean cabled observatory can be in excess of €120 m (ESONET, 2004). Coastal cabled observatories are under development at several locations in European coastal waters, including France, the UK and Ireland.

6.1.1 Buoyed systems

The monitoring of acoustic emissions from cetaceans or measurement of underwater noise is often limited by noise generated from the monitoring vessel. To overcome this problem for certain types of application, a remote passive monitoring system is used which can be deployed and left on station for periods from days to months. The system has been developed for the monitoring of cetaceans around oil platform well heads just before explosive decommissioning is carried out. The system utilises a very stable buoy platform to mount two vertical hydrophone arrays. These hydrophone arrays are suspended below the buoy, with the data from the hydrophones processed within the buoy and transmitted via a radio link to the monitoring vessel or base. The buoy contains its own

Table 6.1. Summary of cabled observatories worldwide.

Cabled network	Location	Main research themes	Description
NEPTUNE (North East Pacific Time-Series Undersea Networked Experiments)	Vancouver Island, British Columbia (extending across the Juan de Fuca plate)	Earthquakes, plate tectonics, fluid flow in the seabed, marine processes, climate change and deep-sea ecosystems	Connected to the shore via underwater fibre optic cables, allowing the opportunity to access all data recorded by the instruments in real time. The system provides free Internet access to data (live and archived).
VENUS (Victoria Experimental Network Under the Sea)	Saanich Inlet and the Strait of Georgia	Oceanographic variables, including salinity, temperature, currents, gas content, ambient sounds, water turbidity and zooplankton abundance	Sea-floor Instruments record and deliver real-time information via fibre optic cables to the University of Victoria. The project utilises a remotely Operated Vehicle ROPOS (the Remotely Operated Platform for Ocean Sciences). Access to VENUS data is free at http://www.venus.uvic.ca .
JAMSTEC (Japan Agency for Marine-Earth Science and Technology) – DONET and DONET2	Kumanonada off Kii Peninsula, Japan	Earthquake, geodetic and tsunami observation and analysis and disaster reduction and mitigation	DONET consists of 300 km of backbone cable system, five science nodes, and 20 state-of-the-art submarine cabled sub-sea measurement instruments deployed along the sea floor at 15- to 20-km intervals. DONET2 will consist of a 450-km backbone cable system, with two landing stations, seven science nodes and 29 observatories.
European Sea Floor Observatory Network (ESONET)	Arctic, Norwegian margin, Nordic Seas, Porcupine/Celtic, Azores, Iberian Margin, Ligurian, East Sicily, Hellenic, Black Sea	Sea-floor processes, geophysics, geotechnics, chemistry, biochemistry, oceanography, biology and fisheries	Comprises 5,000 km of fibre optic sub-sea cables linking observatories to the land via junction box terminations on the sea floor. Provides instantaneous real-time hazard warning and long-term archiving of data for tracking of global change around Europe. Direct measurements of movements of the earth's crust from seismometers.
LIDO (Listen to the Deep Ocean Environment)	Worldwide	Cetacean biosonar and mitigating the effects of noise pollution	Developed by taking advantage of existing networks of underwater observatories. Accesses data in real time via the internet. Antenna systems allow sounds to be echo located and displayed on radar. Plans to develop technology in the near future that would send off alarms whenever cetaceans are approaching areas with high noise levels.

battery power supply system that can be controlled remotely enabling the battery life to be conserved when hydrophone data are not required. The buoy transmits six channels of data covering the 2–200 kHz frequency band. The data from the two arrays can be processed to give range and direction of cetaceans from the buoy.

Buoyed systems can adopt either a single-point or two-point mooring system. The advantage of using a two-point mooring system is that it has a smaller watch circle (less position displacement once moored). A

two-point mooring will only move in a single plane, whereas a single-point mooring could end up at any point within a given radius of its anchor.

6.1.2 Sonobuoys

Sonobuoys were first deployed during the Second World War. The need to detect submarines was paramount and so a cheap (costing between €1,000 and €5,000) expendable form of detecting underwater noise was invented. The life of and the transmission feasible by the sonobuoy were extremely limited but thanks to new technologies, such as the transistor and

miniaturisation of technology, the sonobuoy has become a much more practical and effective form of recording underwater noise. However, it should be noted that sonobuoys are designed to scuttle after operation and so have environmental consequences.

At present there are three different types of sonobuoys:

1. **Active sonobuoys** emit sound energy (pings) into the water and measure the time it takes for an object to echo the sound back to it and transmit the data via VHF to a plane or ship in the vicinity.
2. **Passive sonobuoys** do not pollute the water with noise but only listen as the sound wave hits the hydrophone, is converted into electrical energy and recorded. They also use VHF to communicate with aeroplanes.
3. **Special-purpose sonobuoys** relay various types of oceanographic data to a ship, aircraft, or satellite. There are three types of special-purpose sonobuoys in use today. These sonobuoys are not designed for use in submarine detection or localisation and include the bathythermo (BT) buoy, search and rescue (SAR) buoy and the air transportable communication (ATAC) buoy which is used to communicate between submarine and aircraft.

The low frequency and ranging (LOFAR) buoy is a passive acoustic sonobuoy that can detect acoustic energy from 5 Hz to 40 kHz. This buoy can work at depths of up to 400 feet (~122 m) and for up to 8 h. It is the logical choice for a sonobuoy to be used as it has the ability to pick up frequencies much lower than most hydrophones.

6.1.3 VHLF

The VHLF is a low-frequency hydrophone that is used for general-purpose audible range monitoring. The VHLF operates within one of two frequency ranges – the VHLF-10 operates between 10 Hz and 20 kHz, while the VHLF-200 operates between 200 Hz and 20 kHz. Both of these hydrophones receive acoustic signals at very low frequencies. They have an omnidirectional horizontal beam pattern and have a maximum functional depth of 100 m. They are both

active hydrophones with a preamplifier gain of 40 dB with a 12 V DC power supply. Interfacing these hydrophones to signal analysis equipment would also need to be factored into any plans to use this technology.

6.2 Existing Irish Infrastructure

There is a considerable amount of existing infrastructure deployed in Irish waters from which ocean noise measurements could be made. There are several platforms deployed in Irish waters that routinely collect meteorological or oceanographic data including the Irish Marine Weather Buoy Network, the Irish National Tide Gauge Network and the SmartBay Galway network. These platforms are already fitted with a comprehensive suite of instruments and have the capacity to be fitted with a set of hydrophones (subject to power budgets not being exceeded). Most parameters are available in real time and with the possibility of adding additional parameters to the data message.

6.2.1 Marine weather buoys

The Marine Institute currently has a network of observation buoys around Ireland ([Fig. 6.1](#)) logging and transmitting data either in real time or retaining data for collection by a dedicated research vessel or an opportunistic vessel.

Typical parameters measured by the Irish Marine Weather Buoy Network are atmospheric pressure, humidity, air temperature, wind speed and direction, wave statistics, temperature and salinity. The buoys are configured to transmit data via the Iridium satellite network on an hourly basis. Sentinel platforms (e.g. Buoy 6 at the Porcupine Bank and other scientific and navigation buoys) could provide marine noise monitoring in the areas of concern such as in the vicinity of seismic surveying and known shipping lanes in Irish waters. There is a potential role for the Irish Naval Service in the context of data collection. This could include either unilateral Naval Service data collection or downloading data from Marine Weather Buoys as appropriate.

6.2.2 Galway Bay acoustic buoy

Buoy-based systems can provide high temporal frequency sampling from fixed locations. A recent

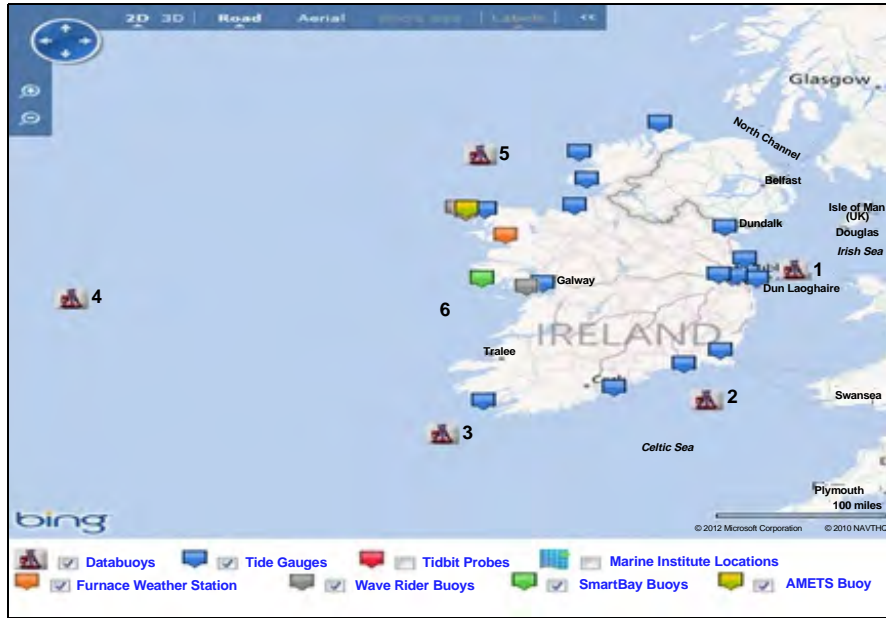


Figure 6.1. The network of existing marine observation buoys around Ireland.

research and development project involving IBM, Biospheric Engineering Ltd, the Sustainable Energy Authority of Ireland (SEAI) and the Marine Institute in Galway Bay has developed an acoustic monitoring buoy to monitor the entire marine noise spectrum and to transmit the hydrophone and particle velocity data in real time to shore, where it is analysed using a stream analytics technique developed by IBM. The acoustic equipment is mounted in the vicinity of a benthic lander frame beneath the buoy that is cabled to the surface

buoy for real-time data transmission via a point-to-point radio link. The intention of the project is to have a 1-year time series of marine noise data that is available to the research community for further analysis.

6.2.3 Cabled systems

Under the Galway cable and SmartBay Galway projects there are plans to deploy a short (4 km) cable to offshore scientific nodes ([Fig. 6.2](#)).

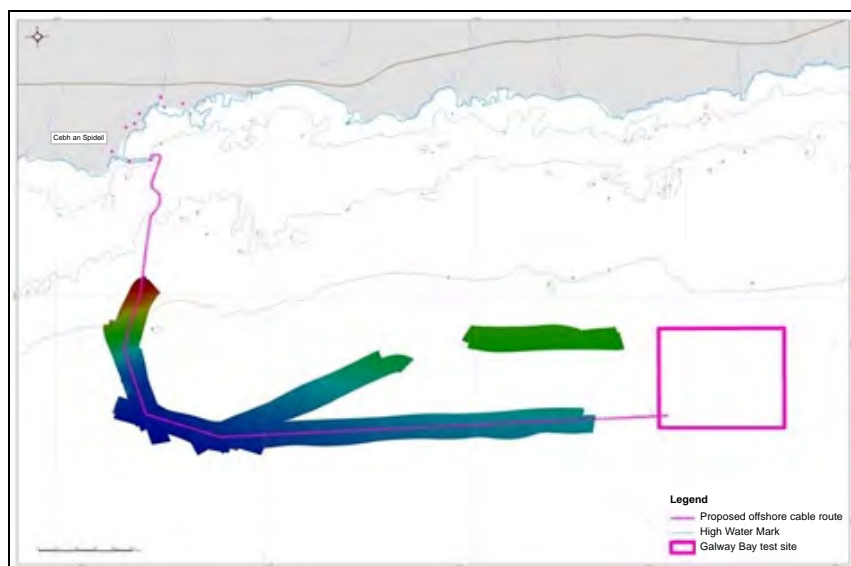


Figure 6.2. Indicative route(s) for the Galway Bay cable project off Spiddal. Wave energy test site shown as pink box (image courtesy of Marine Institute).

The primary purpose of the cable is to provide a test and demonstration facility to ocean energy and marine information and communication technology researchers. The cable will split between the ocean energy and the marine technology applications. It will provide a 400 V direct current and 1 gigabit Ethernet communications to users of the system. Removing the constraints of limited power and data transmission capability is a key aim of this infrastructure.

SmartBay also maintains a wireless network of platforms, primarily buoy-based systems with an array of marine sensors (Table 6.2). There are two possible uses of the SmartBay infrastructure in a marine noise context. Firstly, contextual environmental data are collected that may be relevant to marine noise monitoring (e.g. temperature, density, current velocity and wave heights). Secondly, marine noise sensors could be deployed at appropriately located SmartBay platforms in Galway Bay. Having a ‘silent’ mooring is key to the success of such a deployment. This typically means a move away from chain mooring towards moorings primarily composed of rope.

For MSFD purposes, only measurements at 40 Hz to 10 kHz (not 200 kHz on the SEAL buoy) are required so there are possibilities of small A/D system deployments from some of the SmartBay buoy platforms.

6.2.4 Commissioners of Irish Lights Infrastructure

The Commissioners of Irish Lights (CIL) maintain a network of lighthouses and buoys for navigation and

warning purposes (Fig. 6.3). Some of the CIL platforms may have the potential to be exploited and fitted with other instrumentation, including equipment to monitor for acoustic noise.

There are currently 66 lighthouses and 149 buoys still in use by the CIL. There are many different types of buoys on the water such as port and starboard buoys, cardinal buoys, beacons, leading lights, danger marks and safe water marks. Not all of these have the capacity to take on any extra instrumentation, but some do have the physical capacity to carry extra weight. However, the battery life of the platform would need to be taken into account if these platforms were to be considered for long-term monitoring instrumentation.

CIL moorings are typically designed to withstand large storm and swell waves in Atlantic conditions. Moorings tend to be primarily composed of chain and as a result they are noisy platforms. With modification, some CIL platforms could be considered for short-term deployment of self-contained devices. Lighthouses could have two uses in marine noise monitoring. If a cabled solution was available locally, the lighthouse could be a monitoring location but could also be used as an onshore ground station for small buoys located offshore acting as an antenna for a buoy streaming back data by radio link.

6.2.5 Ferrybox-type platforms

While shipping has been identified as one of the principal sources of marine noise, it is also worth noting that ships can also act as marine research and

Table 6.2. Instruments deployed on each of the SmartBay buoys.

Sensors	Mace Head	Mid-Bay	Inverin	Spiddal	Galway Harbour	Inis Mór
Temperature	Y	Y	Y			
Salinity	Y	Y	Y			
Fluorescence	Y	Y	Y			
Oxygen		Y				
Particulate carbon dioxide	Y					
Water sampling		Y				
Wave	Y	Y		Y		
Currents	Y	Y				
Tide					Y	Y

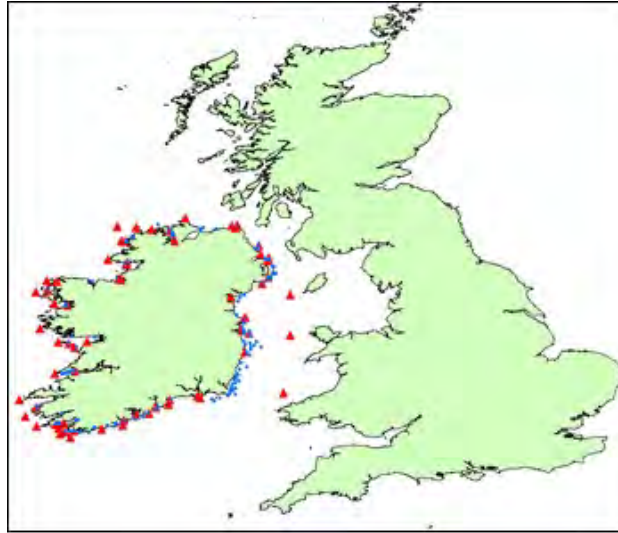


Figure 6.3. Locations of each platform owned and operated by the Commissioners of Irish Lights (CIL). The blue dots represent buoys and the red triangles represent lighthouses (courtesy CIL).

monitoring platforms. It is common to equip ferries and other ships of opportunity with marine sensing equipment to monitor a variety of parameters, including temperature, salinity, chlorophyll, dissolved oxygen, carbon dioxide partial pressure (PCO_2) and pH. The European ferrybox project has enabled this activity on a European shelf seas scale. It would be worth considering a pilot project to assess the suitability of high-frequency ferries for routine marine noise monitoring (<http://www.ferrybox.com>). Ferryboxes are likely to be very noisy platforms. However, they could act as a data collection system from buoys fitted with recording equipment. The data are stored on the buoy and transferred in high speed bursts when a suitable vessel is close by. It would be pertinent to consider the use of Irish Naval Service vessels in the opportunistic deployment and retrieval of pop-up buoys.

A pilot project instrumenting a ferrybox as a relay station for short burst data from a nearby buoy platform with hydrophone equipment in the Irish or Celtic Sea may be considered. Short-term deployments of self-contained equipment on such platforms will give a 'snapshot' of the current situation.

6.3 Equipment Appraisal

A national strategy for monitoring marine noise should be developed that would collect data on a variety of temporal and spatial scales. This is likely to employ

different technologies to broaden spatial coverage and may possibly include cabled applications that give high temporal resolution of marine noise at key locations. To assess suitable hardware and software that could be part of the long-term ambient noise monitoring network in Irish waters, which is to be in place by 2014 in accordance with the MSFD, information was sought from acoustic equipment companies and institutions worldwide using a detailed questionnaire. The questionnaire was designed to determine whether equipment was readily available that could make use of existing Irish infrastructure, thus reducing costs and maximising profitability of existing monitoring systems. The survey was an extensive appraisal of noise monitoring equipment, taking into consideration the following:

- Cost analyses;
- Equipment specification and capability;
- Deployment recommendations;
- Servicing requirements;
- Technical solutions;
- Software availability; and
- Customer service.

Fifteen companies/institutions were identified as being suitable for undertaking the equipment appraisal

survey, one of which was Quiet Oceans. This is a company based in France with expertise in underwater noise forecasting, risk assessment and consulting services to reduce the impact of noise on biodiversity. It has previously deployed noise monitoring equipment in Irish waters as part of an EPA study with University College Cork. Further information on this work can be found in the full project report (Sutton, 2013) and is not presented here. Additionally, the UPC LAB, which specialises in real-time monitoring of ocean noise and cetacean bioacoustics, has deployed equipment in Irish waters as part of this project (see [Chapter 5](#)) and has devised an extensive protocol of best practice for ambient noise monitoring in Irish waters which is outlined in the following section. Of the remaining companies, six equipment appraisals were completed and have been summarised in [Appendix 1](#).

6.4 Protocol of Best Practice and Recommendations

This section describes a protocol designed by the UPC LAB. Implementation would allow Ireland to comply with the noise criteria defined in the MSFD (Descriptor 11). It is noted that there does not yet exist a formal procedure with minimal requirements to comply with the MSFD noise criteria. The measurement protocol described below takes into account monitoring of marine mammals, which is not required by the MSFD itself but may have an application with respect to the Habitats Directive. This part of the protocol could be ignored, although it would make the acquired data much more valuable to scientists at a relatively small extra cost, in addition to providing necessary baseline data to further assess the possible effects of high noise levels in certain areas. All prices quoted in this document are subject to change and do not include VAT.

6.4.1 MSFD Descriptor 11

The definition of the 11 MSFD descriptors is open for interpretation. The following two subsections describe how these descriptors are interpreted in this proposal and what measures are necessary to be in accordance with the Directive.

6.4.1.1 Criterion 11.1

Criterion 11.1: Distribution in time and place of loud, low and mid frequency impulsive sounds

Indicator 11.1.1: Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as SEL (in dB re 1 $\mu\text{Pa}^2\text{-s}$) or as peak SPL (in dB re 1 $\mu\text{Pa}_{\text{peak}}$) at 1 m, measured over the 10 Hz to 10 kHz (11.1.1) frequency band.

From the description of Indicator 11.1.1 it is not clear what a significant impact is, or which thresholds should be used for the SELs, SPLs, or source levels. Until a defined protocol is agreed upon by EU partners, the following approach is suggested:

1. Identify received SELs that are considered harmful based on published literature, e.g. 183 dB re 1 $\mu\text{Pa-s}$ based on TTSs in some dolphin species (Southall et al., 2007).
2. Identify the activities that are most likely capable of producing an environmental impact; these are mainly caused by high-intensity impulsive sources such as piledriving and air-gun operations and other high-intensity sources such as some sonar activities and explosions.
3. The operators of activities identified in item 2 above should provide information on source levels and positions for each day of their operations.
4. Combining the data submitted under item 3, a map of all operations over a calendar year should be created.
5. For each day of a particular operation, the area (divided in suitable cells) where SELs exceed those defined in item 1 above should be mapped.
6. A map should be created that sums the number of days over all operations during the calendar year of each cell where the received levels were exceeded.

Criterion 11.1 is not further considered in this section as it has been examined in detail in [Chapter 3](#).

6.4.1.2 Criterion 11.2

Criterion 11.2. Continuous low frequency sound

Indicator 11.2.1: Trends in the ambient noise level within the third octave bands 63 and 125 Hz (centre frequency) (re 1 μ Pa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate.

A difficulty with this second indicator is that establishing a (statistically significant) trend may take many years. From an environmental point of view, it is important to collect information that not only allows the establishment of a trend in the future, but that also allows characterisation of the current noise levels. It is likely that new insights in the future concerning animal welfare will require different or additional indicators to be computed. The data that are collected under this criterion should provide some flexibility to compute or estimate these new indicators. The following approach is recommended:

1. Areas of interest should be identified and include those that house or are regularly visited by protected species (including marine protected areas, e.g. SACs) and those that have increasing economic activities (such as harbours or zones marked for production of wind/tidal energy). Areas suitable for modelling are those that have a homogeneous environment with a relatively simple bathymetry. Ideally, all modelling would be validated with on-site measurements, but this is especially important for more complex areas, which would then need measurement equipment installed. Areas that are especially suitable for measurement are those that contain resident cetaceans. Modelling will not include unknown or unexpected sources, while measuring will include incidental high-impact sources and in addition can allow real-time monitoring of an area. Measuring will also be important when a mitigation protocol needs to be implemented (e.g. during piledriving activities).
2. Apart from collecting environmental data on sound propagation (sound speed profile in water and in the sea bottom), it is also important to collect:
 - Reports provided under Criterion 11.1;
 - AIS data, especially ship tracking data, and all information that can identify the type of ship; and
 - Information on (fishing) activities, through VMS, by ships too small to carry AIS.
3. For measuring RMS SPL, a snapshot of 10 s is recommended. Additional data should be collected as follows:
 - Whenever possible and practical, all raw acoustic data should be archived;
 - The snapshot (10 s SPL) should be implemented for the whole recording duration; and
 - The hourly and daily averaged SPL and 5th, 50th and 95th percentiles should be computed from the snapshots. An example of the presentation of sound measurements is shown in [Fig. 6.4](#).

6.4.2 Areas for potential deployment

As previously mentioned, monitoring sites under the MSFD should target those areas that experience economic (human) activities or are marked as protected areas (e.g. SACs). Ireland has one operational offshore wind farm at the Arklow Bank. Any future construction site would be an obvious candidate on which to install measurement equipment. A proposed future wind farm is highlighted on the east coast of Ireland, close to a recently proposed cSAC for harbour porpoise and hence would provide an ideal monitoring site. Additionally, once the LIDO equipment is deployed it can provide real-time measurements and source detections (www.listentothedeep.com).

From a marine mammal conservation point of view, there are at least three designated SACs where noise could be monitored. First, Roaringwater Bay is interesting due to its vicinity to Buoy 3. Making measurements in the Bay might allow relating an increase in sound levels at Buoy 3 to sound level changes in the Bay or changes in animal behaviour. Another location with the same species (especially grey seals and harbour porpoises) as found in Roaringwater Bay is the Blasket Islands, which could serve as a reference point in case a relationship is

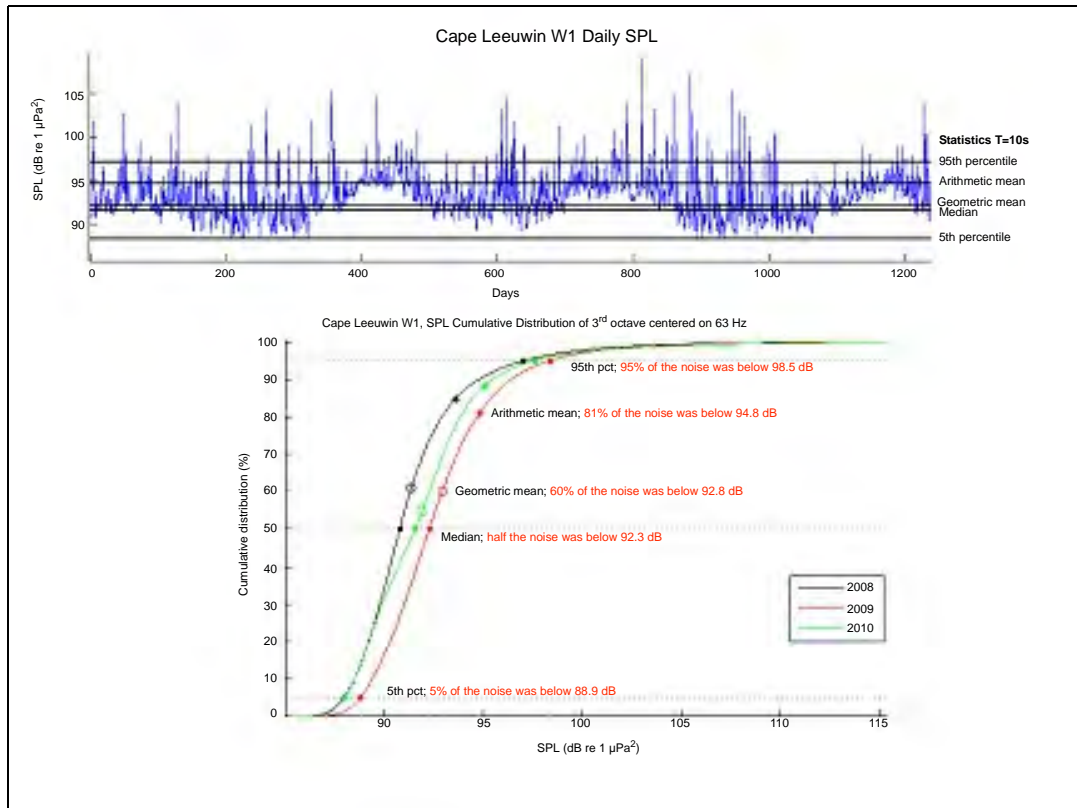


Figure 6.4. Example of noise measurement results from Cape Leeuwin Comprehensive Test Ban Treaty Organization (CTBTO) data (2008–2010). Top: daily averaged sound pressure levels (SPLs) with different statistic outlines. Bottom: distribution of the data per year with the same statistics highlighted. Seasonal cycles may be found with 1 or 2 years of data. A significant trend may need many more years of data (Dekeling et al., 2013).

suspected between measurements made at Buoy 3 and Roaringwater Bay. A third area of interest is the Shannon Estuary. A monitoring location in the Bay would allow following of dolphin behaviour and changes in noise levels caused by merchant vessels and the ferry services.

According to data from the IWDG cetacean atlas (see [Chapter 3](#)), there is a high number of fin whale sightings along the south coast of Ireland. Buoys 2 and 3 are well placed to be able to detect these whales. All measurement locations suggested so far are in shallow waters and relatively close to the coast. Data Buoy 4 is positioned close to deeper waters and may be able to record the presence of species such as sperm and blue whales, in addition to conducting noise measurements. While it would not be immediately necessary for the MSFD, installing a recorder at Buoy 4 would be interesting from a scientific

perspective. The proposal to make use of the existing data buoys assumes that these do not contain equipment that produces continuous noise, such as an Acoustic Doppler Current Profiler (ADCP) with a 1-s duty cycle.

6.4.3 Acoustic modelling

Modelling the sound levels in or near one of the bays or island groups around the Irish coast is considered too difficult or unreliable to perform without being able to validate the model (i.e. making recordings at different spots using calibrated sound sources to characterise the environment). However, further away from the coast, the bathymetry is fairly flat and sound level estimates could be made based on modelling. If the required data (described in [Section 6.4.1.1](#)) are collected, then specific points can be selected and the averaged SPLs estimated. In addition, noise maps can be made that show SELs throughout the area that is

being modelled. To validate the modelling that could be performed at Position 6 in [Fig. 6.1](#) and other locations of interest, it is suggested to collect the same shipping activity data at Positions 2 and 3, together with the recordings. To improve the data coverage at Buoy 3, the installation of an AIS receiver may be necessary. Installation of AIS antennae is not considered here as the Irish Government already has access to AIS data. Since the estimated SPL that would be used to detect a trend is a direct function of the number and types of ships that pass through the area, it is suggested to also look for trends in shipping activity.

An example of SEL estimation based on AIS data is given in [Fig. 6.5](#) for the Barents Sea. The MSFD would require estimating the noise only in one or a few spots. Estimating the SPL due to shipping activities throughout the year at Spot 6, including validation of the modelling approach using data from, e.g., Buoys 2 and 3 (AIS and acoustic recordings), would cost ~€8,000. This includes creating noise maps around Spot 6, such as in [Fig. 6.5](#).

6.4.4 Measurements

6.4.4.1 Battery-powered systems

The MSFD does not require continuous recordings to be made, nor will these be necessary to obtain an understanding of noise levels or noise trends in an

area. Continuous recordings are more important when there is a need to detect the presence of particular sources such as cetaceans, e.g. when mitigation is necessary.

Amongst commercially available recorders, the LAB has selected a series of technical criteria (including hydrophone sensitivity, frequency bandwidth, self-noise level) that ensure fulfilling the MSFD Descriptor 11.2 requirements ([Tables 6.3–6.6](#)). For the purpose of this proposal, this study considered the lowest cost commercially available solution as well as a specific MSFD custom solution developed by the LAB (SONS-D11, <http://sonsetc.com>). The Instrument Concepts (ic) Ocean Sonics icListen low-frequency sound recorder offers a sampling frequency suitable for noise monitoring under the MSFD objectives but does not allow detecting dolphins/porpoises and most cetacean species except baleen whales. Unfortunately, this unit does not support a duty cycle and records continuously thus requiring an additional battery pack and a data logger for longer deployments. The LF (low-frequency) model is sensitive to very low frequency noise (<1 Hz), which can affect measurements when the hydrophone can move with the swell, such as with a deployment from a buoy. This noise may be filtered out from the recordings as long as there is no saturation of the signal; otherwise, Ocean Sonics advises the use of the HF (high-frequency) model.

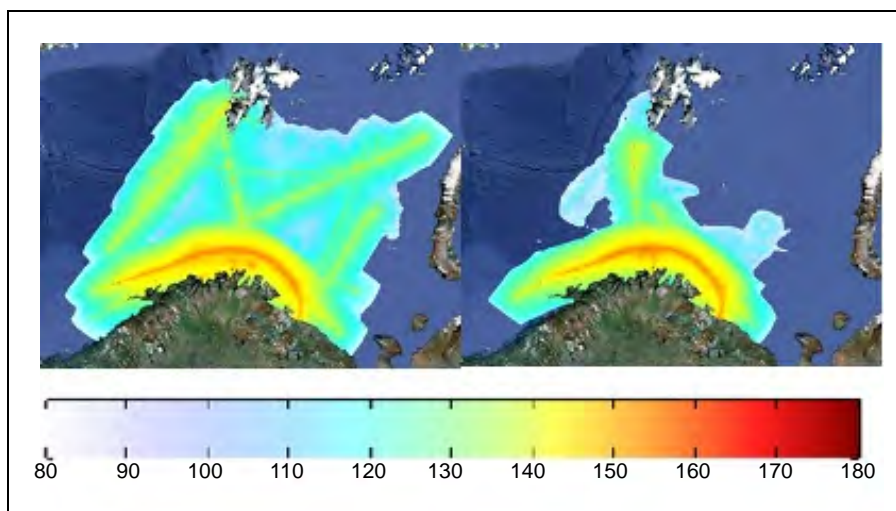


Figure 6.5. One month's cumulative sound exposure level (SEL in dB re 1 µPa-s) estimation (63 Hz) in the Barents Sea in August 2012 (left) and January 2013 (right).

Table 6.3. Ocean Sonics LF configurations (Ocean Sonics icListen LF¹).

Duration (months)	Duty cycle (min/h)	Total recording hours	Data collection (24 bit, 1 kHz sampling)	Power requirement (est.) ²	Storage medium	Recorder price estimate
1	60	720	7 GB	93 Wh	Internal	€7,500
3	60	2,160	22 GB	280 Wh	Internal	€7,500
6	60	4,320	43 GB	561 Wh	External ³	€7,500
12	60	8,640	87 GB	1,123 Wh	External ³	€7,500
1,500 Wh battery pack; 30 m depth rating; may need additional long cable to reach the hydrophone						€2,600
¹ 200 m depth rating; 3,500 m rating model: €9,500. ² Needs battery pack. ³ Needs data logger.						

Table 6.4. Ocean Sonics HF configurations (Ocean Sonics icListen HF¹ (requires data logger with battery pack)).

Duration (months)	Duty cycle (min/h)	Total recording hours	Data collection (24 bit, 32 kHz sampling)	Power requirement (est.)	Storage medium	Recorder price estimate
1	10	120	40 GB	155 Wh	External	€8,500
3	8	288	92 GB	390 Wh	External	€8,500
6	6	432	140 GB	622 Wh	External	€8,500
12	4	576	185 GB	940 Wh	External	€8,500
¹ 200 m depth rating; 3,500 m rating model: €10,500 For a battery pack, see Table 6.5 .						

Table 6.5. LAB battery packs and data loggers (data loggers and battery packs¹ available from the LAB).

	Battery capacity	Storage space	Price
Battery pack (48 alkaline D-cells)	700 Wh	0 GB	€6,500
Battery pack (72 alkaline D-cells)	1,000 Wh	0 GB	€8,500
SONS-DCL Data logger ² (48 Li-SOCl ₂ D-cells)	1,600 Wh	600 GB SSD	€14,000
Optional housing pressure testing			€450
¹ PREVCO aluminium housings rated down to 1,100 m; surface-deployed battery packs (from a buoy) can be custom designed. ² Alkaline battery version available for reduced deployment durations. Delivery times 16–18 weeks.			

Table 6.6. RTSsystem recorder configurations.

Duration (months)	Duty cycle (min/h)	Total recording min (h)	Data collection (24 bit, 40 kHz sampling)	Power requirement (est.)	Storage medium	Recorder price estimate
1	10	7,200 (120)	50 GB	100 Wh	SD card	€14,000
3	8	17,280 (288)	120 GB	250 Wh	SD card	€14,000
6	6	25,920 (432)	180 GB	700 Wh	SSD	€ 22,000
12	4	34,560 (576)	240 GB	900 Wh	SSD	€22,000 ¹
¹ 700 m depth rating.						

To obtain data that can be used for other scientific purposes, such as cetacean detection, a higher sampling frequency is required. The Ocean Sonics icListen HF model can be configured with a duty cycle reducing the requirement on battery power and external storage. The LAB has asked the National Physical Laboratory (NPL) to evaluate the self-noise of the HF system, which is provided in the supporting document (André and van der Scharr, 2013).

Ocean Sonics equipment can be configured and managed through a software package called Lucy (price €2,800). Alternatively, a LAB data logger is available to configure the Instrument Concepts device and download its data. In addition, LAB data loggers come with the SONS-DCL software that is designed to analyse both online and offline data. In any case, for battery deployments, it is advised to process the data offline to save battery power and increase deployment time. A description of the SONS-DCL software package is provided below in [Section 6.4.4.5](#) and complementary information can be found at <http://sonsetc.com>.

An alternative to the Ocean Sonics recorders is the real-time system (RTSystem) recorder, which comes with its own battery power and storage space. The LAB is currently working with RTSystem to ensure that the self-noise of its system with an AGUAtch hydrophone is at or below the ambient background noise at sea state 0.

The prices indicated in [Table 6.5](#) are an estimation that includes an NPL spot-calibrated AGUAtch scientific noise measurement hydrophone. The increase in price is due to a change in the type of recorder. Longer deployment or recording times require more storage space and battery capacity and thus a larger housing. It is possible to equip the recorders with additional battery packs to increase the duty cycle.

Both the Instrument Concepts icListen HF and the RTSystem recorders are capable of recording very high frequency acoustic signals, such as beaked whale or harbour porpoise echolocation sounds, but the suggested configurations ([Tables 6.3](#) and [6.5](#)) will not allow their detection. If there is an interest in detecting these species then the above tables need to be adjusted accordingly. The systems would need to be

configured with a higher sampling rate and larger battery packs to maintain the duty cycle and deployment duration.

6.4.4.2 Externally powered systems

When longer duty cycles are required, offshore acquisition systems can be powered by solar panels and inshore systems may be cabled. For the purpose of compliance with the MSFD descriptors it would not be necessary to extend the suggested duty cycles shown in the above tables. If there is an interest in detecting acoustic sources then a minimum duty cycle of 10 min/h should be considered.

A cabled system can record continuously and can present analysis in real time over a communication network. Depending on the location (e.g. distance to shore), the complete acquisition system can be installed underwater with only a power and data cable (e.g. fibre optics) running to a junction box onshore. Alternatively, a hydrophone can be installed underwater connected to processing equipment onshore through an analogue cable; in that case, the distance to shore must be small (<100 m) and, ideally, the system should be deployed from a jetty (e.g. the Shannon 3G data acquisition). While being cheaper, this has the disadvantage that the cable may pick up more noise. The standard LIDO data processing consists of noise measurements for the MSFD, detection of acoustic events, creation of spectrograms to allow easy human validation of detected sources and access to a live compressed audio stream. The price for a complete cabled system is €18,000. This cost does not include the cable cost and its deployment. It is possible to connect one of the autonomous recorders described in [Tables 6.3–6.5](#) directly to the processing equipment, with an additional cost of €8,000 to the cost of the recorder.

The use of solar panels on offshore acquisition systems allows for longer recording times and possibly transmission of data to shore in contrast to autonomous recorders. The requirements for the buoy strongly depend on the deployment location. The cost for a robust data acquisition buoy with solar panels and battery back-up power that can sustain rough sea conditions starts at €50,000, without mooring costs.

6.4.4.3 Collaborations

The LAB collaborates with the following companies or entities:

- SONSETC, Making Sense of Sounds, company, a spin-off of the LAB, integrates and commercialises software and hardware solutions developed at the LAB (<http://sonsetc.com>).
- The NPL is hired to calibrate the hydrophones that are used especially for noise measurements. This is essential for the noise measurements to be accepted under the MSFD.
- For deployments in complicated areas (rough seas), the LAB collaborates with Mobilis (www.mobilis-sa.com) to provide a suitable buoy and mooring system.

6.4.4.3 Equipment specification and capability

All hydrophones will be spot calibrated by the NPL. The NPL list price will be charged to the customer without any additional fees. When appropriate, the whole acquisition system can be calibrated. It is advised to recalibrate the hydrophone after 5 years or when a strong trend in the acquired levels is detected. Calibration is normally done before shipment, although, depending on availability of the NPL and the time restriction of the customer, it can be performed after a first deployment.

The acoustic sound recorder can be configured through a web interface. If the recorder is bought through the LAB, then the configuration is set and tested before shipment. Configuration can be done by a non-expert and does not require any specific training. A pre-deployment step-by-step protocol for configuring and testing a recorder will be provided.

6.4.4.4 Deployment recommendations

The sound recording systems can be deployed up to 700 m depth (depending on the final selection of the sound recorder). However, for the purpose of the MSFD, care should be taken not to install a hydrophone inside a deep sound channel. This is likely not to be an issue close to the Irish coast. The hydrophone should be positioned around 30 m depth or, in the case of shallow water, in the centre of the water column.

In complicated deployment scenarios, it is recommended to previously simulate the mooring situation to advise on the best choice regarding buoy size and mooring. In that case, the LAB collaborates with MOBILIS to offer this solution.

The acoustic recorder can be clamped to the mooring cable of an existing or newly deployed buoy or, alternatively, the recorder can be attached to the buoy itself and the hydrophone clamped to the mooring cable. The latter may facilitate servicing operations. Ideally, Dyneema® cabling is used for the mooring to avoid chain noise, although this noise may be above the frequencies of interest of the MSFD.

If a strong current is likely to be present, then the recorder with a hydrophone should be placed at a position with minimal current, with a combined Ethernet and power cable running to a station on the jetty. All components and cables should be firmly fixed to the jetty platform to avoid clapping or banging sounds and cable wear. If the current is 'normal', then the hydrophone can be installed in the water, with an analogue cable running to the station on the jetty. The hydrophone can be suspended in the water column using a tensed mechanical cable with the hydrophone clamped to the cable (see [Chapter 5](#)).

6.4.4.5 Servicing requirements and data analysis

[Tables 6.2–6.5](#) summarise the battery life and recorded data size for different recording duty cycles. Towards the end of the estimated deployment period, the batteries should be replaced. Data may be copied from the recorder over an Ethernet connection. There is no difference in file size for quiet and noisy locations – there is no compression of the 24-bit data. The battery life depends on the water temperature and the initial condition of the batteries. To maximise the deployment time, it is advised to use new (but tested) non-rechargeable batteries for each refit. The recorded raw data are stored in standard wav files and can readily be opened by audio processing software such as Audacity, Adobe Audition, PamGuard or Raven.

To automatically manage and process raw data, the LAB offers the following services:

- Importation of data from different platforms; data stored sorted per platform;

- Computation of noise measurements in 10-s snapshots; hourly and daily average SPLs; 5th, 50th, 95th snapshot percentiles;
- Detection of impulsive and short tonal acoustic events;
- Creation of spectrograms of all data to allow human supervision of measurement results;
- Creation of compressed MP3 audio files to listen to data segments for verification of audible acoustic events;
- Automatic creation of graphics and summaries of the analysis results that can be integrated into an MSFD report;
- An interface to retrieve analysis results and to compare results from different platforms; the interface is networked and data can be accessed locally or globally over the Internet;
- Export of analysis results in CSV format;
- Integration of AIS data and visualisation through a Google maps plugin (when data are available, see example below); and
- Integration of information provided by companies under MSFD Descriptor 11.1.

Automated reporting can only provide a factual overview of the data, not an interpretation of the measurements. All services can be provided from the LAB and can be made available to the customer through an interface accessible over the Internet. The data results can be made public or their access can be password protected.

To process data in real time, the LAB provides the customer with a processing server that should be installed close to the hydrophone. The digitised acoustic data (a sound recording system is considered to be already installed or is bought separately) is passed to the server usually over an Ethernet connection, but other data connections can be considered. All analysis that needs to be performed on the acoustic data is done by the server and only the analysis results are then transmitted to the LAB from where they are made available. If requested, all raw

data (and other results) can be recorded and stored locally by the server as well. The customer is responsible for providing an Internet connection to transfer analysis results to the LAB. The cost for these services is €5,000 per platform per year, which includes rental of the server and use of the LIDO website. Installation of the server is normally straightforward and can be done by personnel at the location with remote support from the LAB (e.g. Skype or telephone). Once a network connection is available, any further configuration can be done from the LAB. Travel costs to the installation location, if required, are not included. The customer can send drives with data to the LAB where the data will be processed and made available through the LIDO website. This service costs €3,000 per platform per year. When data from a large number of platforms need to be analysed, certain discounts may apply.

A customer has the option to purchase a private LIDO server that can perform the data analysis and includes the LIDO interface to view the results ([Fig. 6.6](#)); in addition to CSV exports, software such as Matlab can also connect directly to the MySQL database on the server through Open Database Connectivity (ODBC) to process analysis results. Depending on the customer needs, the server will be able to handle various acoustic data formats (normally wav). Specific configurations can be prepared for individual recording locations, for example to detect a particular source, or a general configuration can be used that resamples data to a default sampling frequency and then performs standard processing. The cost of a private server is €15,000, which includes 1 year of support for data processing and server maintenance (the LAB will need to be able to access the server remotely).

The raw acoustic data are stored in wav format in the device. The storage medium is a secure digital (SD) card or solid state drive, depending on the configuration. The storage medium can be removed from the recorder to be copied or archived, or the data can be transferred over an Ethernet cable.

Automated reporting will not be able to comment on or interpret the measurements. If requested, the LAB can provide a complete summary report on measurements and detections. If the customer has already licensed

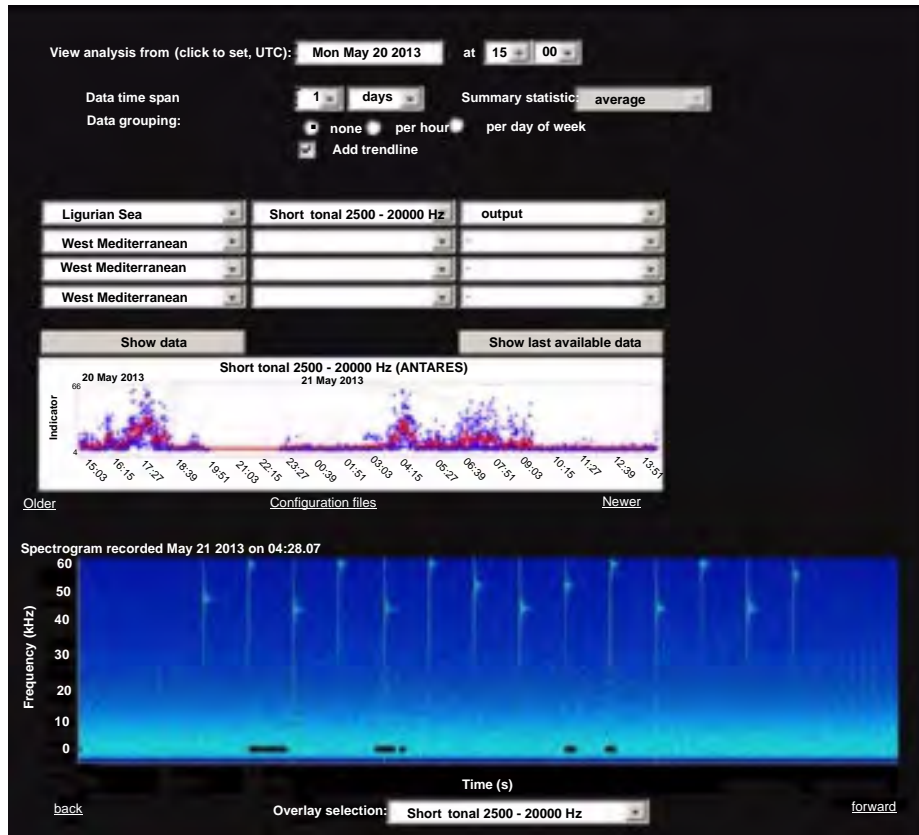


Figure 6.6. Example of Listen to the Deep Ocean Environment (LIDO) interface. Analysis results can be viewed from any recorded time period, together with a graph showing trends and spectrograms of snapshots.

LAB analysis software, a report costs €2,500 per platform per year. If the customer does not yet have a licence for standard data analysis, then a report costs €6,000 per platform per year.

Note: it may not be possible to detect statistically significant trends in data until after a few years of data have been recorded.

6.4.4.6 Procurement

[Tables 6.7](#) and [6.8](#) provide data on the procurement of equipment. [Table 6.7](#) provides information on equipment available for purchase, while [Table 6.8](#) lists equipment for rent.

6.4.4.7 Shipment

The processing of an order for a sound recorder may be up to 12 weeks. This depends on suppliers and the time availability of the NPL to perform hydrophone calibration. At the customer’s request, equipment can be tested ‘dry’ by deploying it inside the LAB and

providing the customer with remote access to the recorder, or it can be tested ‘wet’ by deploying the recorder at the OBSEA Observatory at 20 m depth to ensure proper functioning before shipment.

- The processing of an order for a private LIDO server or an online processing server will be 4–6 weeks.
- Providing services for offline data analysis, modelling, or reporting will typically take 1 month to complete.
- Shipment costs to Ireland, including insurance, are normally around €500.

6.4.4.8 Total cost example scenarios

The costs for a scenario where one of the data buoys is equipped with a long-deployment recorder and all data are analysed by the LAB are given in [Table 6.9](#), while those for deployment from a jetty and real-time

Table 6.7. Equipment available for purchase.

Equipment	Price	
RTSystem recorder – small battery compartment	€14,000	700 m depth
RTSystem recorder – large battery compartment	€22,000	700 m depth
icListen LF with battery pack.	€16,000	200 m depth; if a surface-deployed battery pack can be used the price is reduced by about €5,000
icListen HF with battery pack	€17,000	As above
icListen configuration software	€2,800	
icListen HF with SONS-DCL data logger	€22,500	Allows offline data analysis of recorded data; uses SONS-DCL for configuration; 200 m depth
Data analysis and management server	€15,000	With 1 year support to facilitate import and analysis of acoustic data

Table 6.8. Equipment for rental and services.

Equipment	Price	
Online data analysis and management	€5,000 per platform per year	
Offline data processing	€3,000 per platform per year	Results made available through LIDO site
Sound pressure level estimation and noise maps through modelling	€8,000	For modelling at Spot 6 using data from Buoys 2 and 3 for model validation
	€3,000	For modelling at an additional point with an environment and bathymetry similar to Spot 6
MSFD final report	€2,500 per platform per year	If online or offline data analysis is already done with LIDO
	€6,000 per platform per year	If acoustic data have not yet been analysed

MSFD, Marine Strategy Framework Directive; LIDO, Listen to the Deep Ocean Environment.

connection to LIDO are presented in [Table 6.10](#). The costs for a complete coastal monitoring scenario, with private LIDO server, are presented in [Table 6.11](#).

Note: all purchases and procurement of equipment and services are subject to national regulations, specific guidelines and EU procurement directives.

Table 6.9. Scenario where one of the data buoys is equipped with a long-deployment recorder and all data are analysed by the Laboratory of Applied Bioacoustics, Technical University of Catalonia.

Costs	Price	
One time set-up cost		
Purchase of recorder	€22,000	Includes batteries, shipping and testing at the LAB.
Yearly recurring cost		
Battery replacement	€1,080	Estimate for 54 Li-SOCL ₂ primary D-cells. Alkaline cells would be much cheaper but would require a shorter duty cycle. From second year.
Off-line data analysis	€3,000	
MSFD reporting	€2,500	
First year	€27,000	
Subsequent years	€6,580	

MSFD, Marine Strategy Framework Directive; LIDO, Listen to the Deep Ocean Environment.

Table 6.10. Scenario where deployment is from a jetty and real-time connection to Listen to the Deep Ocean Environment (LIDO).

Costs	Price	
One time set-up cost		
Purchase of recorder	€8,500	icListen HF
Power/data cable	€750	Depends on required length
Yearly recurring cost		
LIDO subscription	€5,000	Includes hardware to perform data analysis on-site. Network connectivity is the responsibility of the client
MSFD reporting	€2,500	
First year	€13,750	
Subsequent years	€7,500	
MSFD, Marine Strategy Framework Directive.		

Table 6.11. Complete coastal monitoring scenario, with private Listen to the Deep Ocean Environment (LIDO) server.

Cost	Price	
One time set-up cost		
Recorders for Buoys 1, 2, 3 and 5	€88,000	Four RTSystem long-deployment recorders
LIDO server	€15,000	
Yearly recurring cost		
Battery replacements	€4,320	From second year
LIDO server support	€2,500	From second year
Modelling of Spot 6	€8,000	Also performs modelling at Spots 2 and 3 for validation
MSFD reporting (1, 2, 3, 5, 6)	€10,500	
First year	€121,500	
Subsequent years	€25,320	
MSFD, Marine Strategy Framework Directive.		

7 Research Outputs

This project has highlighted a number of potential avenues for the assessment of ocean noise in Irish waters and through trial deployments has increased capacity within Ireland for the implementation and operation of an ambient noise monitoring network under the MSFD. The project has been actively disseminating results through conference presentations, report publication, outreach programmes and media coverage. A dedicated project website has been active at <http://www.monitoringoceannoise.com> throughout the project duration.

7.1 Publications

Beck, S., O'Brien, J., O'Connor, I. and Berrow, S.D., 2013. *Assessment and Monitoring of Ocean Noise in Irish Waters*. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland. 1–28 pp.

7.2 Conference Presentations

Beck, S., O'Brien, J., Berrow S., André, M. and O'Connor, I., 2012. *Assessment and Monitoring of Ocean Noise in Irish Waters*. ICES 2012, Bergen, Norway.

Beck, S., O'Brien, J., Berrow, S., André, M., O'Connor I. and Wall, D., 2013. *Assessment and Monitoring of Ocean Noise in Irish Waters*. European Cetacean Society 2013, Setubal, Portugal.

Beck, S., O'Brien, J., Berrow, S., O'Connor, I. and Wall, D., 2013. *Assessment of Impulsive and Continuous Low Frequency Noise in Irish Waters*. International Conference on the Effects of Noise on Aquatic Life, Budapest, Hungary.

O'Brien, J., Beck, S., Berrow, S., André, M., van der Schaar, M. and McKeown, E., 2013. *The Use of Deep Water Berths and the Effect of Noise on Bottlenose Dolphins in the Shannon Estuary cSAC*. International Conference on the Effects of Noise on Aquatic Life, Budapest, Hungary.

7.3 Recognition for Research Work

Nominated for Best Poster Presentation:

Beck, S., O'Brien, J., Berrow, S., André, M. and O'Connor, I., 2012. *Assessment and Monitoring of Ocean Noise in Irish Waters*. ICES 2012, Bergen, Norway.

7.4 Outreach Programmes

- Ocean noise was the main theme at the GMIT Young Scientist Exhibition stand in January 2012, RDS, Dublin.
- Delivered to schools in the Galway region during the Young Scientist Galway event held at the GMIT in May 2013.
- The project engaged in public awareness and education through <http://www.monitoringoceannoise.com> and also through www.listentothedeepocean.com, whereby the first real-time acoustic monitoring was carried out in Ireland. Ship tracking through an AIS system was also operational at the site and the site had increased hits from Ireland due to the project ([Table 7.1](#)).
- Additionally, the project website was set up at www.monitoringoceannoise.com and, up to the period June 2013, in excess of 10,000 visitors have accessed the site. [Figure 7.1](#) depicts the number of visitors to the project website.

7.5 Media Coverage (National and Regional)

- RTÉ News visited the real-time monitoring site in the Shannon Estuary in July 2012 and interviews with the project team were aired on the 6 pm and 9 pm RTÉ News on 20 July 2012.
- An article on the project by Pat Flynn was published in the *Irish Times* on 3 August 2012.
- An article on the project by David Murphy was also published in the *Irish Daily Mail* on 4 August 2012.
- The project team gave an interview to Mary Kennedy from RTÉ's Nationwide as part of the GMIT's 40th anniversary celebrations and this was aired on 2 November 2012.
- Radio interviews by the team were given with local radio stations in the Shannon Estuary region – Radio Kerry and Clare FM – in August 2012.

Table 7.1. Numbers of visitors from Ireland to the Listen to the Deep Ocean Environment (LIDO) website during the project.

Location	No. of visitors	Average duration
Dublin	451	00:02:03
Galway	149	00:00:30
Limerick	39	00:01:06
Cork	19	00:01:07
Dundrum	12	00:00:48
Killarney	12	00:02:04
Mullingar	10	00:02:32
Tralee	6	00:11:10
Shannon	4	00:00:46
Leixlip	4	00:00:00
Total	736	00:01:45



Figure 7.1. Visitors to the project website.

8 Recommendations for Implementation and Uptake of Research Findings

- This desk-based study was aimed to help Ireland meet the requirements of the MSFD (2008/56/EC) under Descriptor 11.
- Under the EU MSFD, Ireland as a Member State is expected to have established and implemented a long-term noise monitoring programme by 2014.
- Further study is required to implement and assess the performance of noise monitoring equipment on an ongoing basis.
- Such monitoring could also contribute towards Ireland's reporting requirements under other directives, thus ensuring a cost-effective approach, e.g. using noise monitoring equipment to cover monitoring requirements under the EU Habitats Directive for vocal species such as cetaceans.
- Methods already used to assess noise in Irish waters should be continued at regular intervals to allow for the analyses of trends, including all licensed activities emitting low to mid-frequency impulsive sound.

Table 8.1. Recommendations for implementation and uptake of research findings.

Item to implement/ assess	Recommendation	Target	Time frame
Establish and implement a monitoring programme under the Marine Strategy Framework Directive (MSFD) (by 2014)	Use existing infrastructure if possible. Target areas that experience economic activities or areas that are marked as Special Areas of Conservation. Data could also be gathered to inform legislators of other policies, such as the EU Habitats Directive. Continually monitor and assess the monitoring strategies employed to ensure a cost-effective programme for Irish waters	<ul style="list-style-type: none"> • Marine Institute • Department of Agriculture, Food and the Marine (DAFM) • Commissioners of Irish Lights • Department for the Environment, Community and Local Government (DECLG) • National Parks and Wildlife Service (NPWS) • Irish Whale and Dolphin Group • Environmental Protection Agency (EPA) 	Long term
Seismic analysis	The assessment and quantification of seismic survey metadata should be maintained in order to calculate the proportion of days on which target sounds are recorded in an area and to continue spatial overlay with cetacean coastal and offshore sightings. Continue producing noise maps. Continue to analyse the seismic data with the peak-to-peak pressure amplitude in order to highlight areas subjected to high noise levels.	<ul style="list-style-type: none"> • Petroleum Affairs Division (PAD) • NPWS • DECLG • EPA 	Long term
AIS and VMS spatial analyses	Vessel Monitoring System (VMS) and Automatic Identification System (AIS) spatial analyses repeated annually to continue to explore trends in Irish waters highlighting noisy and quiet areas. Continue to produce noise maps.	<ul style="list-style-type: none"> • DAFM • Irish Naval Service • Department of Transport, Tourism and Sport (DTTS) • DECLG 	Long term

Table 8.1 contd

Item to implement/assess	Recommendation	Target	Time frame
Noise monitoring	Continue to update a register of licensed activities emitting low to mid-frequency sound within the Irish Exclusive Economic Zone (EEZ).	<ul style="list-style-type: none"> • EPA • DECLG • NPWS • DAFM • Irish Naval Service 	Long term
Joint register/ Regional reporting	Continue to liaise with the Joint Nature Conservation Committee (JNCC) to achieve regional reporting between Member States – Ireland and the UK. This will be very informative in the long term once the UK has processed its seismic survey data. As noise produced in UK waters will travel into Irish waters, regional reporting will account for this.	<ul style="list-style-type: none"> • JNCC • DECLG • EPA 	Long term
Impact of noise on aquatic marine fauna	Future studies should focus on the effects that the main noise sources identified in Irish waters have on various marine fauna. This approach should be ecosystem based to ensure that a concise understanding is achieved and impacts can be properly mitigated.	<ul style="list-style-type: none"> • EPA • DECLG • NPWS 	Long term
Metadata library of acoustic data sets gathered to date in Irish waters	Continue to update the library of acoustic data sets collected in Ireland to date. This will allow the DECLG to respond to developments under MSFD implementation in a cost-effective manner and such data sets could serve as baseline data.	<ul style="list-style-type: none"> • DECLG • NPWS • Marine Institute 	Long term
Continually acquire cetacean distribution data	Such data will allow managers to make informed licensing decisions based on the identification of regions and periods where sensitive species are not present or are present in low densities and therefore minimise exposure to anthropogenic noise and reduce the detrimental impacts of habitat loss.	<ul style="list-style-type: none"> • DECLG • NPWS • PAD • EPA 	Long term
Physiological and behavioural impacts of noise on marine fauna	Effects on acoustic communication have been noted for a number of species in response to vessel noise. Masking is a key concern under Indicator 11.2.1 (low frequency continuous noise) and highlighting areas and species of concern is a first step towards successful mitigation.	<ul style="list-style-type: none"> • DECLG • NPWS • DTTS • Irish Naval Service 	Long term

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Acronyms

2D	Two-dimensional
3D	Three-dimensional
ADCP	Acoustic Doppler Current Profiler
AIS	Automatic Identification System
ANTARES	Astronomy with a Neutrino Telescope and Abyss environmental RESearch
ATAC	Air Transportable Communication buoy
BT	Bathythermo-buoy
CIL	The Commissioners of Irish Lights
CITES	The Convention on International Trade in Endangered Species
CMRC	Coastal and Marine Research Centre
CPU	Central Processing Unit
cSAC	Candidate Special Area of Conservation
CTBTO	Comprehensive Test Ban Treaty Organization
DECC	Department of Energy and Climate Change
DONET	Dense Ocean-floor Network System for Earthquakes and Tsunamis
EEZ	Irish Exclusive Economic Zone
EIA	Environmental Impact Assessment
ESONET	European Sea Floor Observatory Network
EU	European Union
GES	Good Environmental Status
GMES	Global Monitoring for Environment and Security
GMIT	Galway-Mayo Institute of Technology
HF	High Frequency
ic	Instrument Concepts
IMO	International Maritime Organisation
IOSEA	Irish Offshore Strategic Environmental Assessments
ISCOPE	Irish Scheme for Cetacean Observation and Public Education
IWC	International Whaling Commission
IWDG	Irish Whale and Dolphin Group
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JNCC	Joint Nature Conservation Committee
LAB	Laboratory of Applied Bioacoustics

LF	Low Frequency
LIDO	Listen to the Deep Ocean Environment
LOFAR	Low Frequency and Ranging
MMO	Marine Mammal Observer
MMSI	Maritime Mobile Service Identity
MSFD	Marine Strategy Framework Directive
NEPTUNE	North East Pacific Time-Series Undersea Networked Experiments
NPL	National Physical Laboratory
NPWS	National Parks and Wildlife Service
NRC	National Research Council
ODBC	Open Database Connectivity
OSPAR	The Convention for the Protection of the Marine Environment of the Northeast Atlantic
PAD	Petroleum Affairs Division
PAM	Passive Acoustic Monitoring
PBR	Peak-to-bubble ratio
PCO₂	Carbon dioxide partial pressure
pH	Power of hydrogen
P-P	Peak-to-peak
PReCAST	Policy and Recommendations from Cetacean Acoustics, Surveying and Tracking
psi	Pounds per square inch
PTS	Permanent Threshold Shift
RLP	Regional Legal Person
RMS	Root mean square
RT	Real-time
SAC	Special Area of Conservation
SAM	Static Acoustic Monitoring
SAR	Search and Rescue buoy
SBC	Single board computer
SD	Secure digital
SEAI	Sustainable Energy Authority of Ireland
SEL	Sound Exposure Level
SIIM	Scientific Instrument Interface Module
SPL	Sound Pressure Level
TSG	Technical Sub-Group
TTS	Temporary Threshold Shift

UNCLOS	United Nations Convention on Laws of the Sea
UPC	Technical University of Catalonia
VENUS	Victoria Experimental Network Under the Sea
VHF	Very High Frequency
VHLF	Low-frequency hydrophone
VMS	Vessel Monitoring System

Appendix 1 Equipment Appraisal

Table A1.1. Equipment appraisal.

	Company/Institute	Company/Institute	Company/Institute	Company/Institute	Company/Institute
Equipment	Cornell Lab of Ornithology	Cornell Lab of Ornithology	Multi-Électronique	Loggerhead Instruments	JASCO Applied Sciences
Device name	MARU (Marine Autonomous Recording Unit) 'pop-ups'	Auto Detection Buoy	AURAL M2 (long-deployment type)	DSG-Ocean	Autonomous Multichannel Acoustic Recorder (AMAR)
Detecting frequencies	Maximum recording bandwidth 2 Hz to 30 kHz	Maximum recording bandwidth 10 Hz to 4 kHz		400 kHz (200 kHz bandwidth) in duty cycle mode, 80 kHz in continuous recording mode	Maximum recording bandwidth 0.1 Hz to 340 kHz
Duty cycle	Variable from 16% to 100%	Continuous operation	Programmable duty cycle or continuous recording	Programmable duty cycle or continuous recording	Programmable duty cycle
Self-noise	Some self-noise due to electromechanical operation of the recording and storage system	Minimised by using specialised 'gumby' buoy mooring system	Some self-noise that should be considered	Approximately 50 dB re 1 $\mu\text{Pa}^2/\text{Hz}$ above 100 Hz	The system self-noise with a M8E high gain hydrophone sampling at 16 Ksps is less than 32 dB re 1 $\mu\text{Pa}^2/\text{Hz}$ on the 24-bit channels
Deployment					
Submerged weight	10 kg in salt water	Surface buoy	Approximately 20.9 kg	2.7 kg negative. Aluminium housing is 5.4 kg negative	1 kg (not including batteries)
Dimensions	Height: 48.3 cm Diameter: 58.4 cm	See supporting documents	Height: 177 cm Diameter: 14.6 cm	Housing: Height: 63 cm Diameter: 11 cm Hydrophone extends 14 cm	Height: 57.15 cm Diameter: 16.5 cm
Mooring and deployment configuration	See supporting documents	Construction, deployment and maintenance of buoy and mooring by the Woods Hole Oceanographic institute (WHOI)	See supporting documents	See supporting documents	See supporting documents
Deployment depth	Maximum: 6,000 m Acoustic recovery depth maximum: 2,500 m	Typically 17–500 m	Maximum: 300 m	PVC: Maximum: 160 m Aluminium: Maximum: 2,000 m	Two designs: 1 Maximum: 250 m 2 Maximum: 2,500 m
Security	MARU-specific acoustic transponder Optional ARGOS tracking system	On-board redundant GPS for asset tracking	Not applicable	Mounts are type 316 stainless steel, and resistant to corrosion	Acoustic releases and optional Satellite Locating Beacons

Table A1.1 contd

	Company/Institute	Company/Institute	Company/Institute	Company/Institute	Company/Institute
Servicing requirements					
Maintenance	Refurbishment of MARUs at Cornell. Replacements provided for continuous long-term recording when batteries are exhausted and/or when the memory is full	Service every 5 months to replace batteries	Basic maintenance including rinsing device, formatting hard drive and replacing batteries, sacrificial anodes and desiccant bags	Basic maintenance including cleaning of bio-fouling and replacement of O-rings (provided) every year	Basic maintenance including cleaning of bio-fouling and replacement of batteries. Calibration needs to be periodically checked
Data retrieval	Extract sound files from flash storage. Data provided to customer on hard disk drive (HDD)	By telemetry using iridium satellite constellation, 2,400 baud. Bulk data available as EXT3 formatted USB flash drive	Extract sound files from flash storage	Extract sound files from flash storage	Recovering device and connecting via a custom Ethernet adapter cable (Comms Box)
Acoustic file size	Two 64 GB compact flash cards	Customisable	Variable	In continuous record mode, the user sets the file size (e.g. 10 MB)	Approximately 1.76 TB
Data storage	Two 64 GB compact flash cards	Up to 128 GB	640 GB (2 x 320 GB HDD)	128 GB secure digital (SD) card	Maximum 1.76 TB
Power supply	83 D-cell alkaline batteries	Custom large battery pack, 18 V, 8 kWh alkaline pack	12 V DC nominal (9 V DC to 15 V DC)	Either 24 alkaline D-cells, or rechargeable lithium battery packs	There are four modular battery options of alkaline or lithium batteries. Power adapter for laboratory or ship-board setting
Battery life	Variable. Example continuous recording time @ 2 kHz Sample rate = 175 days	Variable. Example continuous recording time @ 2 kHz = 6 months	Variable. Example continuous recording time @ 128 Hz = 140 days	Variable. Example continuous recording time 20 kHz = 36 days Recording at 20 kHz, sampling 1 min every 10 min will last 365 days	Variable. Durations of several days to over 1 year have been fielded

Table A1.1 contd

	Company/Institute	Company/Institute	Company/Institute	Company/Institute	Company/Institute
Technical solutions					
Use of existing structures	MARUs can be moored in many configurations	Possible, but never done with an Auto Buoy	Not applicable	The DSG mounting brackets can be modified to mount to any structure.	The AMAR is designed to be easily integrated within existing structures and systems
Suitability for Irish waters (inshore and offshore)	MARUs are capable in Ireland's sea conditions. Experience includes 2010 project at Rockall Trough to study beaked whales, pilot whales and anthropogenic noise working with the Irish Whale and Dolphin Group (IWDG)	Buoys have been deployed off Boston, Jacksonville and in the Chukchi Sea Alaska. Projects have successfully deployed and recovered Auto Buoys in these conditions. Special moorings or need for design changes for Irish Sea conditions can be established at time of project	About 200 AURAL-M2 have been deployed over the last 10 years, everywhere in the world, including Canada, USA, Europe, Antarctica, among others	The DSG-Ocean has been used worldwide in coastal oceans	AMARs have been used in rivers, harbours, coastal waters and in the deep ocean. AMARs have been used extensively in the Arctic
Software availability					
Specialised software	Raven Pro and XBAT	Custom auto detection software	AURAL Setup and InfoWAV	Haystack	AMARlink proprietary software and Spectroplotter
Software requirements	Typically run on PC	Serial console for unit interface, system capable of mounting EXT3 file system and web browser	Compatible with Microsoft Windows 2000, XP and 7	Compatible with Microsoft Windows XP, 7 and 8	Compatible with Microsoft Windows
Data format	.wav, .aiff	Compressed FLAC audio files	.wav	.dsg. A software program is provided to convert these to .wav files	.wav and .csv
Data analysis	Cornell Bioacoustics Research Program (BRP) can provide complete data management, analysis and reporting based on project needs	Web interface for browsing audio clips and viewing spectrograms on any networked computer. Expert clip checking and full data analysis provided by Cornell	Not applicable	Data analysis with Haystack is intended to be straightforward, automatically incorporating the calibration data in the files to calculate noise levels from all recordings	
Analysis of historic acoustic data	Raven and XBAT support analysing historical data including .wav files	Not applicable	Not applicable	Haystack does not currently support .wav while in beta release. Full version (summer 2013) will support .wav files	Acoustic data are in .wav format and other oceanographic sensor data are in .csv format after download from the AMAR

Table A1.1 contd

	Company/Institute	Company/Institute	Company/Institute	Company/Institute	Company/Institute
Customer service					
Troubleshooting	Cornell BRP leases MARUs, providing a spare MARU with each lease in case of damage during shipment or problems in the field. In the unlikely event of equipment problems resulting in loss of data, the BRP will provide replacement units in an effort to complete the project	Periodic 'health and status' reports confirm proper function. Dashboard display of real-time alert status and buoy health	User troubleshooting and FAQs can be found at http://multi-electronique.com/auralm2_en.htm . info@multi-electronique.com or 418-724-5835 can also be contacted	Provided free of charge personally by Dr Mann, who has 25 years experience in marine acoustics. Contact is available at all times via email and phone	The AMAR typically does not require troubleshooting in the field. If it does, the Users Manual includes typical problems that new users seem to encounter. Telephone support is typically available 24/7
Warranty	BRP field technicians are experienced in the issues that occur during MARU deployment and recovery at sea. Technicians travel with equipment and supplies, which allows for repair of many minor issues in the field. The client is responsible for any damage or loss to the MARUs during the deployment	BRP field technicians are experienced in the issues that occur during deployment and recovery at sea. Technicians travel with equipment and supplies, which allows for repair of many minor issues in the field	For warranty details http://multi-electronique.com/pages/warranty.htm	1-year full warranty on all parts	1-year full warranty for AMAR
Calibration	All MARU calibration is performed during refurbishment operations at Cornell prior to shipment	Remotely configurable for updating monitoring protocol, reporting schedule, and systems administration	No calibration	The DSG board is calibrated by Loggerhead Instruments, and the hydrophone calibration is provided by HTI	Factory calibration curves are provided and a Piston-Phone Kit for doing field calibration and pre-deployment checks can also be provided
Repairs	All repair and refurbishment is performed at Cornell BRP facilities	Field repair is co-ordinated with the WHOI. Parts of the system can be monitored remotely and service requirements assessed before field trips are required	At Multi-Électronique facility	Will ship replacement units, so that there is no downtime with recording	Repair and overhaul the AMAR at JASCO's facilities in Dartmouth, Nova Scotia, Canada. Some field support can be provided by various worldwide offices – including the office in the UK

Table A1.1 contd

	Company/Institute	Company/Institute	Company/Institute	Company/Institute	Company/Institute
Cost analyses					
Unit cost	MARU lease costs are a combination of fixed and variable costs depending on requirements. See supporting documents	Estimates for an initial year of acoustic monitoring for one Auto Buoy vary from \$300,000 to \$500,000	AURAL-M2 (long model): \$17,400, 640 HDD, no battery included	\$5,940. DSG-Ocean PVC. This includes recorder, PVC housing, hydrophone (HTI 96-min), D-cell battery holder, and 128 GB SD card. \$9,940. DSG-Ocean aluminium housing	The Base AMAR is priced at \$11,000. With typical options an AMAR usually costs/sells for approximately \$25,000
Software cost	A permanent Raven Pro licence is available for \$400. XBAT is open source, available at: www.xbat.org	Near real-time clip checking is included. A permanent Raven Pro licence is available for \$400. XBAT is open source, available at: www.xbat.org	Included in the estimated cost	Scheduling software and wav conversion software are free. Haystack software price is not set yet	The required software is included with the AMAR at no additional cost
Additional hardware cost	Anchors are typically provided and sourced locally by the client to reduce shipping costs	Vessel and deployment costs and shipping costs are not included in this estimate	None	None	Typically, customers add the following to a base AMAR: <ul style="list-style-type: none"> • Extra solid state memory • External battery packs • Mooring components/ accessories The cost depends on the requirement and number of units ordered
Additional information	Cornell BRP is very experienced in deploying MARUs and analysing resulting data in acoustic arrays. The history and strength of BRP's work are focussed on lower frequency marine mammals, particularly the North Atlantic right whale. While MARUs and BRP analysis tools are capable of higher frequency work, the majority of BRP deployments focus on vocalisations under 4 Hz	The Auto-Detection Buoy system provides near real-time detection of vocalisations from marine mammals. On the east coast of the United States endangered North Atlantic right whales are the focus, with 10 Auto Buoys in the shipping lanes into Boston Harbor	AURAL-M2 can have a standard or an alternative battery rack: <ul style="list-style-type: none"> • Standard: insert D-cells one by one. These cells are available everywhere • Alternative: insert battery pack made by and only available from Multi-Électronique Inc. 	Training is available on request, as well as consulting on field deployments. Loggerhead Instruments manufactures all of its electronics and mounting brackets in-house. Hydrophones from HTI are also stocked. Software code running on the DSG recording board is available upon request. The current system was designed to be easy to deploy from a small boat, and can easily be handled by one person. This equipment is also now employed by PIER (Pfleger Institute of Environmental Research) switching from the long-term acoustic recording system (LARS), noting reduced power demands and increased memory capacity of the DSG-Ocean	See supporting documents

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntimid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomhnithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitrealí;
- scardadh dramhuisce;
- dumpáil mara.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí chomhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRSCIÚ AR AN GCOMHSHAOIL

- Monatóireacht ar chaighdeán aer agus caighdeáin aibhneacha, locha, uisce taoide agus uisce talaimh; leibhéal agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdeán aer agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstíúrthóir agus ceithre Stíúrthóir.

Tá obair na Ghníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar inní iad agus le comhairle a thabhairt don Bhord.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.



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