Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE
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Mapping the Spatio-temporal Distribution of Underwater Noise in Irish Waters

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

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EPA STRIVE Programme 2007-2013

Mapping the Spatio-temporal Distribution of Underwater Noise in Irish Waters

(2011-W-MS-7)

STRIVE Report

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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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Executive Summary

Noise arising from human activity ('anthropogenic noise') can be considered an acoustic pollutant, and in recent years noise from human activities such as shipping, seismic exploration surveys[1], seabed-drilling, and sonar has increased significantly in the Irish marine environment. Impacts on marine animals range from death caused by physical injury and auditory damage, to behavioural and habitat-use changes. Sound waves travel very quickly in water and the effects of noise on marine mammals have been detected up to tens of kilometres from noise sources.

The Marine Strategy Framework Directive (MFSD) (adopted in June 2008) is intended to protect the marine environment across Europe more effectively. Its aim is to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend, Descriptor 11 (Noise) being 'anthropogenic sound that has the potential to cause negative impacts on the marine environment'. This research provides verifiable quantification and visualisation of the spatio–temporal distribution of underwater noise to be published for Irish waters necessary for the development of Indicators 11.1 and 11.2 specified in the MSFD.

Multiple data sets capturing the key physical environmental variables were combined with information on anthropogenic noise sources such as shipping and seismic surveying in a modelling framework using Quonops© proprietary software. This approach employed advanced sound-propagation algorithms and statistical techniques to generate robust estimates of the spatio-temporal distribution of noise levels generated by human activities in Irish waters. Regional validation of the modelled noise fields was performed using field data from an acoustic-monitoring array deployed outside Cork Harbour.

1 In the context of this document the term "seismic activities" is used as an abbreviation for seismic geophysical surveys normally undertaken for hydrocarbon prospecting.

The results of the noise-propagation modelling showed that continuous sound from ship traffic noise can spread over very large areas, well beyond the standard navigation routes. Acoustic monitoring outside Cork Harbour highlighted the importance of duty cycle (the percentage of time actively recording) and duration of monitoring in capturing the variability in anthropogenic noise. The overall conclusion is that a monitoring programme should employ short duty cycles but over longer periods of observation. This is an important consideration in the context of capturing the diversity of environmental variables that contribute to the soundscape for a given location. Shorter duty cycles also mean lower power consumption and reduced volumes of data, improving the outlook for compatibility with real-time data transfer for monitoring purposes.

The noise 'footprints' from seismic survey activities are very dependent on the location and season of the survey operation. In general, the footprint from seismic surveys tends to be much larger in deep water where the ambient soundscape is relatively quiet. Risks to marine mammals associated with single airgun shots are localised to the source itself; however, cumulative risks associated with the repetition of shots generates very large areas of potential risk. While the 'pulse-block-days' approach is simple to implement, its appropriateness is questionable given that cumulative noise footprints are much larger and more variable than the current grid used to report 'pulse-days'. The extent of overlap between areas subject to 'cumulative noise risk' and marine mammal distribution in Irish waters highlighted the potential for risk of behavioural changes encompassing marine mammal hotspots. Therefore, it follows that dedicated prediction of noise footprint and biological risks should be mandatory, tightly defined and emphasised in any appropriate assessment for seismic survey activities.

Some key points should be noted:

- Noise-propagation modelling showed that continuous sound from ship-traffic noise can spread over very large areas, well beyond the immediate vicinity of standard navigation routes;

- A noise-monitoring programme should employ shorter duty cycles but over longer observational periods;
- Dedicated prediction of noise footprint and biological risks should be included in any appropriate assessment for seismic survey activities.

1 Introduction

1.1 Background

Since the 1970s, there has been considerable scientific discourse addressing concerns about the potential detrimental effects of anthropogenic noise on marine life. Targeted research in this field began in the 1980s with a number of pioneering studies (Payne & Webb, 1971; Richardson et al., 1985). Since the early 2000s, various scientific institutions, government agencies and intergovernmental bodies have promoted studies in this field which have produced significant amounts of data on the effects of sound on marine mammals (Richardson et al., 1995; Würsig & Richardson, 2002; Popper & McCauley, 2004; Hastings & Popper, 2005; Hildebrand, 2005; National Research Council [NRC], 2003, 2005; Wahlberg & Westerberg, 2005; Thomsen et al., 2006; Madsen et al., 2006; Southall et al., 2007; Nowacek et al., 2007). These studies document the presence, as well as the absence, of physiological effects and behavioural reactions to the various acoustic signals experienced by marine mammals, fish and a number of invertebrate species. They have stimulated further discussion and debate among scientists, stakeholders and political decision-makers regarding effective methods for addressing the potential impacts of underwater noise and thus develop mitigating measures in order to draft future regulations.

Concern stemming from increasing awareness of the potential for negative impacts on wildlife has now become firmly established across all sectors: civil society (International Fund for Animal Welfare, 2008); industry (International Maritime Organisation, 2009); and political bodies (Marine Mammal Commission, 2007; European Parliament, 2004). For Europe, the current regulatory framework arises from two separate directives: the Water Framework Directive (Directive 2000/60/EC) and the Marine Strategy Framework Directive (Directive 2008/56/EC).

The Marine Strategy Framework Directive (MSFD) aims at achieving or maintaining Good Environmental Status (GES) by 2020. It advocates the ecosystem approach to the management of human activities that have an impact on the marine environment, integrating the concepts of environmental protection and sustainable use of marine goods and services for present and future generations. Article 9 of the MSFD requires Member States to determine a set of characteristics for GES for their marine waters on the basis of 11 qualitative descriptors. A list of criteria and methodological standards on GES of marine waters, which is to be used by Member States, was put forward by the European Commission in September 2010. However, the Commission Decision states that research and technical progress is needed to support the further development of criteria in relation to Descriptor 11 (Noise, 'Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment'), and its two Indicators; 11.1 (impulsive loud, low and mid-frequency sounds) and 11.2 (continuous low frequency sounds).

A task group (TG) was established for each of the qualitative descriptors, and the report on the criteria and indicators in relation to Descriptor 11 considers the descriptor to mean 'anthropogenic sound that has the potential to cause negative impacts on the marine environment, which in this case includes component biota but not necessarily the whole environment'. It suggests that 'a systematic inventory of acoustic conditions in regional seas would help in documenting the extent of current noise exposure, and estimating the pristine historical or desired future conditions for the resources. This would help in understanding the impacts of different noise sources in different areas and show differences between regional seas. This comparison will help in making objective decisions of a good or bad environmental status' (Tasker et al., 2010).

Anthropogenic noise is considered an acoustic pollutant, with an anticipated increase through the expansion of shipping, resource extraction and offshore development. Impacts of acoustic pollution on marine biota range from death due to physical injury and auditory damage, to behavioural and habitat-use changes. Marine animals rely on sound for navigation, feeding and communication and are known to be particularly sensitive to anthropogenic noise, with effects being detected over tens of kilometres from sources. Effects depend on various factors, including overlap in space and time with the organism and sound source, duration, nature and frequency content of the sound, received level and context of exposure (e.g. animals may be more sensitive to sound during critical times such as breeding or nursing) (Tasker et al., 2010). In areas with high levels of anthropogenic noise, listening horizons may be significantly reduced (Clark et al., 2009; National Research Council [NRC], 2005).

1.2 Project Objectives

There is currently no programme in place for monitoring marine noise in Ireland and baseline data does not exist. The aim of this research was to provide information necessary for the development of Indicators 11.1 and 11.2 as specified in the MSFD. This required a combination of expertise in data-mining, signal-processing, sound-propagation modelling, and marine biology/oceanography in Irish waters. Specific objectives included:

1. Creation of a database of static environmental parameters, for example bathymetry and sediment for inclusion in models;
2. Assessment of availability and quality of data parameters for inclusion in noise-propagation modelling;
3. Creation of a preliminary 'Atlas of Noise' to address the requirements of the MSFD;
4. Creation of potential risk maps for marine mammals;
5. Identification of priority areas to be monitored through a network of sensors;
6. Drafting of recommendations towards designing an effective noise-monitoring network in Ireland's Exclusive Economic Zone (EEZ) waters;
7. Dissemination of information on the project to a wide range of end users, for example policy-makers, regulators, NGO groups, citizens, business, industry sectors, local authorities and academics;
8. Delivery of a project that is underpinned by robust communications and project-management processes.

2 Noise Propagation and Modelling

2.1 Fundamentals of Underwater Noise

Sound in water is a combination of progressive waves in which water particles are alternately compressed and decompressed. Sound can be measured as a pressure variation within the medium around a point of equilibrium defined by the hydrostatic pressure.[2] This pressure variation (acoustic pressure) acts in every direction with amplitudes that are usually very small compared to hydrostatic pressure. The SI unit for pressure is the Pascal (Pa, Newton per square meter). Another sound measurement is given by the motion component of a particle that provides the displacement (m), velocity (m/s) and acceleration (m/s^2) of the water particles in the medium.

Research undertaken since the 1980s has shown clearly that marine mammals are sensitive to acoustic pressure. It has also indicated that numerous species of fish and invertebrates respond to particle movement generated by acoustic pressure and that this can disturb underwater life at various levels (Sand & Karlsen, 2000; Ona et al., 2007; Sand et al., 2008). Depending on the type of sensory systems they possess, marine life can be sensitive to both pressure and the movement of particles. Owing to the wide range of pressures and intensities, and given marine-life physiology, it is customary to describe sound using a logarithmic scale known as the decibel scale (abbreviation: dB).[3] By definition, the decibel is a relative unit with respect to a reference acoustic pressure level. This reference level is equal to 1 µPa (one millionth of a Pascal) in underwater acoustics. A decibel level therefore only makes sense if its reference is specified. The decibel level corresponds to a non-linear multiple of the reference value.

2 Hydrostatic pressure is the pressure exerted by a fluid at equilibrium due to the force of gravity. It is the pressure exerted by water on the surface of an immersed body; it increases by approximately 1 atmosphere per 10 meters of depth.

3 The decibel is a logarithmic scale of measurement in acoustics. The decibel is defined as $P_{dB} = 20 \log10 (P/P_{ref})$, with $P_{ref.}$ the reference acoustic pressure expressed in µPa, and P the acoustic pressure also expressed in µPa.

Underwater noise levels cannot be compared with airborne noise levels. Indeed, while the reference level is 1 µPa for underwater acoustics, it is 20 µPa in air. Furthermore, unlike air, the ocean environment is considered an incompressible propagation medium as it is approximately 1000 times denser than air. For illustrative purposes, a qualitative scale of underwater noise levels generated at a distance of 1 meter in a low-frequency band of a few kHz is given in Fig. 2.1.

In water, sound waves propagate very rapidly (typically 1500 m/s) and over large distances. The noise-level distribution in the water column and sediments depends mainly on the sources present (natural, anthropogenic or of animal origin), the bathymetric conditions, the conditions of temperature and salinity, the nature of the seabed and the state of the sea. Differences in propagation are therefore often very significant both locally (for example, at a particular point but considering two different water depths) and at the broad oceanic scale.

Pressure can be measured using a pressure-sensitive device such as a hydrophone (an underwater microphone). This responds to the rapid fluctuations in pressure as a function of time. The acoustic signal's speed of oscillation defines its frequency (F), expressed in Hertz (Hz). Sounds have a low pitch at low frequencies (slow oscillations) and a high pitch at high frequencies. Signal-processing techniques exist to analyse acoustic signals based on their frequency, and potentially separate them according to standardised frequency bands known as octave bands[4] or one-third octave bands (the terms 'third octave band' or 'one-third octave band' are used interchangeably) .

To overcome the oscillatory nature of the raw acoustic signal measured, the acoustic energy level is defined as a sound's 'effective' pressure, that is the signal's root

4 One octave is the interval between two sounds whose respective frequencies have a ratio of 2 to 1. A 'one-third octave' is a fraction of an octave. The ANSI S1.11 (2004) standard defines the central frequencies and the characteristics of the filters used to distinguish them.

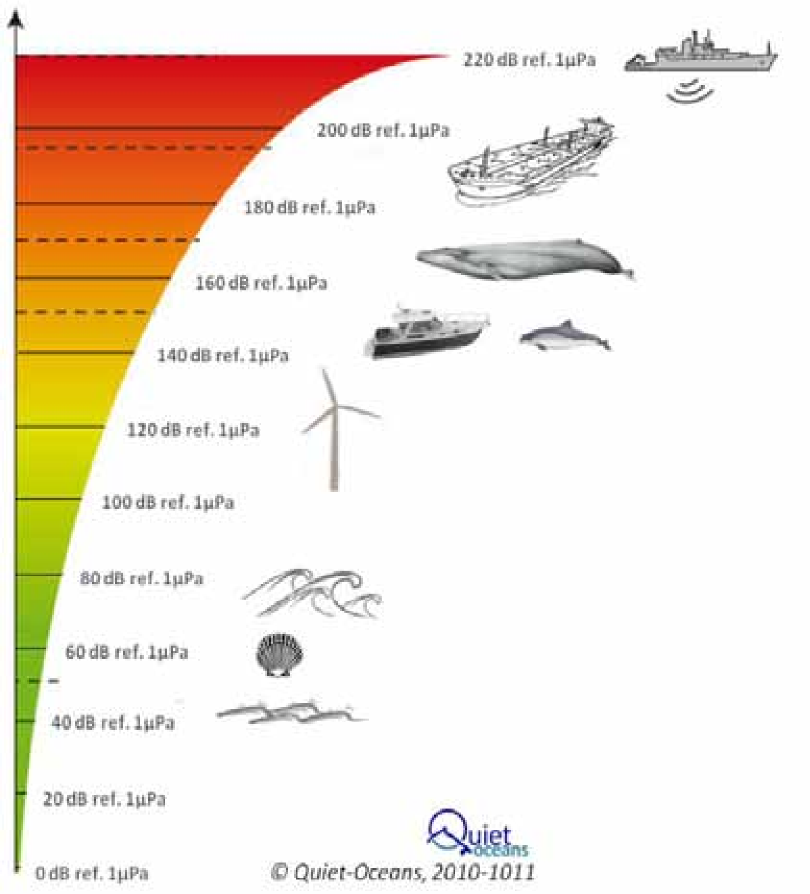


Figure 2.1. A relative scale for comparing qualitative levels of underwater noise emitted at a distance of 1 meter in a low frequency band of a few kHz. Source: Quiet-Oceans.

mean square (RMS) over a given time interval. (Table 2.1 below provides additional descriptions and clarifications of key terms used in this section.) This quantity does provide some information, but it is reductive and insufficient for establishing a sound exposure level (SEL) for marine mammals. Consequently, another way of overcoming the oscillatory nature of the raw acoustic signal measured is to consider the peak-to-peak levels (maximum levels). The perceived sound field depends on the sensitivity of each species. This sensitivity depends on the frequency of the noise or on the hearing function of the species. By way of comparison, the acoustic sensitivity of the human species covers the range of frequencies from a few tens of Hz (frequencies of the lowest perceptible sounds) to approximately 20 kHz (frequencies of the highest perceptible sounds). This sensitivity range reduces with age. The physical quantity used to represent the acoustic sensitivity of each species is the SEL. This corresponds to the integral of the sound energy received within the biological sensitivity frequency band (frequency band effectively perceived by a species) during a given period of time. When the period of noise exposure exceeds 1 second, the relevant quantity is cumulative noise exposure, which is meaningful in terms of impact.

To date, the criteria recently proposed for underwater animals have been developed by Hastings & Popper (2005) and Southall et al. (2007), and are of a two-fold nature as they (i) provide the limits of both peak-to-peak acoustic pressure and (ii) SELs. Ambient noise, in particular if it includes an anthropogenic component,[5] has a stochastic nature by definition.[6] This is linked to the fact that anthropogenic noise sources and some environmental parameters/conditions are difficult to predict. For example, it is particularly difficult to predict when the next fishing vessel will pass through a given position. The percentile concept helps translate and

5 Relating to human activity.

6 A stochastic phenomenon, as opposed to a deterministic phenomenon, is a phenomenon for which only a statistical analysis is suitable.

Table 2.1. Definitions and units.

Name	Definition	Unit
Source level	The emitted sound pressure is the amplitude of the signal that would be generated at 1 meter from a source of noise. This pressure can be expressed as instantaneous value, average value, root mean square (RMS0,[8] value, or maximum value).	dB ref. 1μPa @ 1m
Received level	The sound pressure is the amplitude of received signal that can be measured for a given frequency band by a receiving hydrophone at a given distance from any sound source. This pressure can be expressed in terms of instantaneous RMS or peak value.	dB ref. 1μPa
Received energy level	The energy received is the square of the acoustic pressure of the signal received.	dB ref. 1μPa^2[9]
Sound exposure level (SEL)	This is also known as the Single Event Level. The single-event level of a sound event corresponds to the level of a square pulse with a duration of 1 second, which has the same sound exposure as the sound event.	dB ref. 1μPa^{2}s

quantify this random aspect. A percentile[7] corresponds to the proportion of time and space for which the noise exceeds a given level.

In accordance with the recommendations of the MSFD, this study has been conducted for two one-third octaves centred at 63 Hz and 125 Hz. The bandwidth for each octave or one-third octave, is delimited by the minimum and maximum frequencies (Table 2.2).

Table 2.2. Central frequency and bandwidth around each one-third octave.

Nominal central frequency	63 Hz	125 Hz
$F_{min\ (One\text{-}third\ octave)}$	56 Hz	110 Hz
$F_{max\ (One\text{-}third\ octave)}$	71 Hz	140 Hz

2.2 Effect of Ocean Environment on Noise Propagation and Levels

Noise propagation and ambient noise levels are determined by several factors: bathymetry (underwater terrain); the nature of the seabed (sediment type); oceanographic conditions (such as temperature and salinity, currents and tides); weather conditions such as the wind (and consequently waves); and rainfall intensity. Other parameters also influence noise propagation and level, but to a lesser extent (Table 2.3).

Table 2.3. Effect of physical properties of the ocean environment on acoustic propagation and noise generation.

	Influence noise propagation	Generate noise
Bathymetry	✓	
Bottom parameters	✓	✓
Temperature/salinity	✓	
Tide	✓	
Currents		✓
Wind/waves	✓	✓
Rain		✓

Sound-propagation losses are greater as water becomes shallower, a cumulative loss effect that derives from shoaling caused by changing bathymetry as well as tidal fluctuations. The effect is linked to the interaction of sound waves with the interfaces of the oceanic waveguide (surface and seabed). Furthermore, it should be noted that ocean waves tend to surge as they encounter shallower water, which increases their contribution to ambient noise.

7 This concept is widespread even in everyday life. For example, the average income of the top 10% of income earners or the 'income threshold corresponding to the 90th or to the 95th percentile', i.e. the income earned by the poorest individual among the top 10% or top 15% richest individuals. Meanwhile, the 50th percentile corresponds to the median salary.

8 The Root Mean Square, or RMS, corresponds to the square root of the mean of the squares of the signal over a fixed period of time.

9 Mathematically, dB ref. 1μPa and dB ref. 1μPa2 are identical. We adopt the squared notation to indicate to the reader that the value has been derived via an energy calculation.

Propagation losses are more significant when the seabed is loose and fine-grained (i.e. silt absorbs sound waves better than gravel). However, the denser the sediment, the more reverberant it is; sound waves with significant angles of incidence on sediment are better reflected when the sediment is dense. Wind-generated ocean surface waves propagate and absorb sound waves, an effect that increases with increasing sea state. However, the noise generated by surging waves also increases the level of ambient noise. In other words, rough seas increase natural noise levels, but other noise sources do not carry as far as they would in calm conditions. In shallow water, sedimentary particles are mobilised by currents and/or waves, and noise is generated when sedimentary particles collide with each other. Generally, the coarser and faster the sediments, the higher the noise level.

Temperature and salinity profiles of the ocean vary in space (vertically and horizontally) and time (daily and seasonal trends), and stratification of the water column is a commonly occurring phenomenon. Sound waves are highly sensitive to stratification, and a negative vertical temperature/salinity gradient will result in the refraction of sound waves towards the seabed where they will be subject to the influence of sediment. Conversely, in the absence of stratification (homogeneous medium), sound can carry further because acoustic ray paths interact far less with the surface and/or seabed.

Rainfall exerts a negligible effect on underwater sound propagation, but the sound generated by droplets falling on the sea surface does contribute to an increase in natural noise levels.

Most properties of the water column interactively affect sound propagation and contribute to natural ambient noise. This greatly complicates the establishment of universal dependency rules, which means that modelling is currently the only feasible approach.

The noise footprint of a given seismic exploration operation is defined as ‘the contribution that the operation’s noise makes to the ambient noise’. The following characteristics affect the size of the project’s noise footprint:

- The ambient noise level;
- The level of noise energy introduced in the water by the operation;
- The ease with which the operation's noise propagates with minimum loss; in other words, the operation's range.

Note that conditions that foster the propagation of the project’s noise also foster the propagation of noise from other existing anthropogenic sources (e.g. noise due to maritime traffic, recreational activities or fishing), which also increase the level of ambient noise.

2.3 Modelling Anthropogenic Sound Propagation in the Ocean

Sound waves travel very quickly in water and over distances of a few kilometers to hundreds of kilometers. The lower the frequencies and the deeper the water, the further waves will travel. As previously described, the noise-level distribution in the water column depends mainly on the sources present, the bathymetric conditions, the conditions of temperature and salinity, the nature of the seabed and the state of the sea. A reasonable estimate of the sound fields can only be achieved by numerical simulation using models that take all these parameters into account.

Our approach employs ‘parabolic equation modelling’ or ‘ray modelling’ with a Gaussian energy distribution to accurately translate the geometric distribution of sound in the water column while ensuring computational efficiency for the statistical analysis. Sound-speed profiles in water are proportional to the water temperature, salinity and pressure (or depth). The main effect of these non-homogeneities in sound-speed distributions is to bend the propagation rays and create propagation channels. However, these complex phenomena can be predicted using numerical simulation using Nx2D modelling of sound propagation. This means that the three-dimensional effect is achieved through successive modelling in cylindrically interpolated vertical planes. For ships, sound sources are modelled as point sources near the surface, while seismic airgun sound sources are modelled as point sources at the actual depth provided by the survey operators.

2.3.1 The Ocean Noise-prediction System Quonops©

Quiet-Oceans operates the proprietary Quonops© ocean noise-monitoring and prediction system (Folegot, 2010a) developed and owned by the company. In

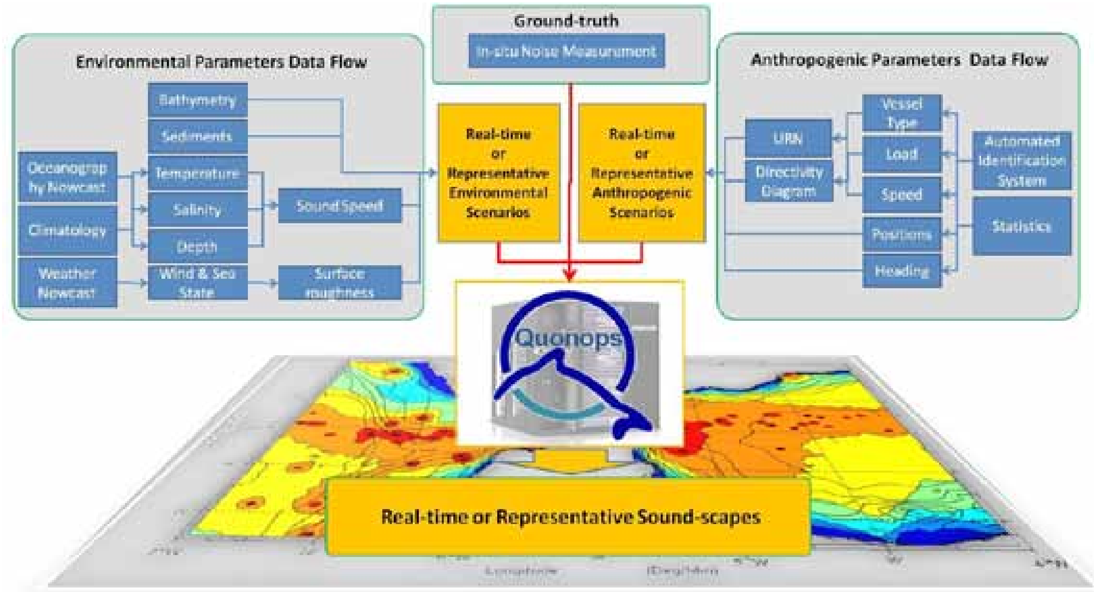


Figure 2.2. Schematic description of the operational platform for predicting anthropogenic noise.

a similar manner to weather forecasting systems, Quonops© produces an estimate of the spatio-temporal distribution of noise levels generated by human activities at sea. The system caters for a broad range of maritime activities, including: maritime traffic (Folegot, 2010b); oil exploration; underwater warfare exercises; offshore construction and fossil-fuel extraction; offshore wind-power construction and operations; underwater drilling and blasting operations. The outputs from Quonops© are tailored to the requirements of existing and emerging national and international regulations regarding underwater noise, the conservation of habitats and marine ecosystems, and the protection of marine species (Folegot, 2010c). The production of statistical soundscapes effectively generates new knowledge and insights on the spatio-temporal distribution of noise pollution. The system also supports underwater noise impact assessments and assists in the formulation of optimised planning and focused mitigation of maritime industrial activities in terms of environmental compliance.

2.3.2 Operational Validation Procedure for Quonops©

It is standard practice in modelling situations to use directly observed environmental and acoustic measurements to provide a locally valid assessment of modelled predictions. Practical experience shows that it is not unusual to encounter sound levels differing by 10 dB at two different depths 10 m apart for a given time. The standard procedure adopted for Quonops© is to integrate localised measurements that have been processed for each one-third octave. Figure 2.3 (b) gives an example of such processing in the case of sound-mapping for the Ushant traffic-separation scheme (France). This work involved the collection of field data off the coast of Ushant Island (Fig. 2.3 [a]). Acoustic recordings were collected in the one-third octave, centred on a frequency of 120 Hz using a hydrophone placed at a depth of 55 m to the south of the traffic-separation scheme (blue curve in Fig. 2.3 [b]). These recordings corresponded very well with values predicted by Quonops© for the same location over an 18-hour period (red curve in Fig. 2.3 [b]). This procedure provides confidence that the sound fields predicted by Quonops©, based on environmental data and human activities for the entire area, are accurate and statistically valid. This research is due to be published, and has been presented at international conferences.[10,11,12]

10 Meeting for an International Quiet Ocean Experiment, August 2011, UNESCO, Paris.

11 ‘Ambient noise in north-European seas: Monitoring, impact and management’ Conference, October 2011, Southampton.

12 SERENADE (Surveillance, Etude et Reconnaissance de l’Environnement par Acoustique Discrète) workshop, April 2012, Grenoble.

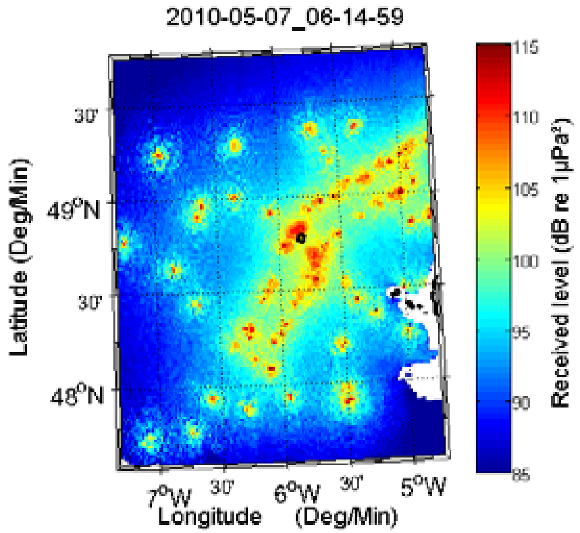


Figure 2.3 (a). Illustration of the low-frequency (125 Hz octave) noise field associated with commercial traffic, fishing, and pleasure activities in the Ushant separation scheme (off the west coast of France) by combining Automatic Identification System (AIS) data flow, and oceanography now-casting as produced by Quonops©.

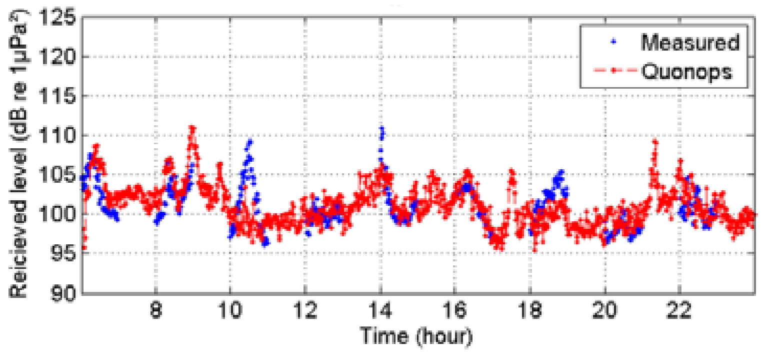


Figure 2.3 (b). Comparison between the noise predicted by Quonops© and the *in situ* measurement made in the vicinity of the south-going route of the Ushant separation scheme.

2.3.3 Maturity of Quonops©

Quonops© is currently in use in a wide variety of national and international projects across the industrial, governmental and research sectors and in a wide variety of environments. Figure 2.4 shows the areas where Quonops© has already been or is currently being deployed.

2.3.4 Methodological Limits

Although consistent with the scientific and technical state-of-the-art, the results presented in this study are of a predictive nature and have not been calibrated against ocean acoustic field surveys throughout the model domain. They therefore represent a viable and feasible assessment of the potential impact of noise. Ultimately, the quality of this predictive assessment is based on:

- A set of hypotheses and approximations that are inherently dependent on the characteristics of underwater sound propagation models developed over more than 40 years in the military sector, and
- The quality of data describing the environment, shipping, and seismic surveying.

This study is also based on data acquired from previous studies, the international scientific literature and acoustic measurement reports. The results of this study are intended for use in:

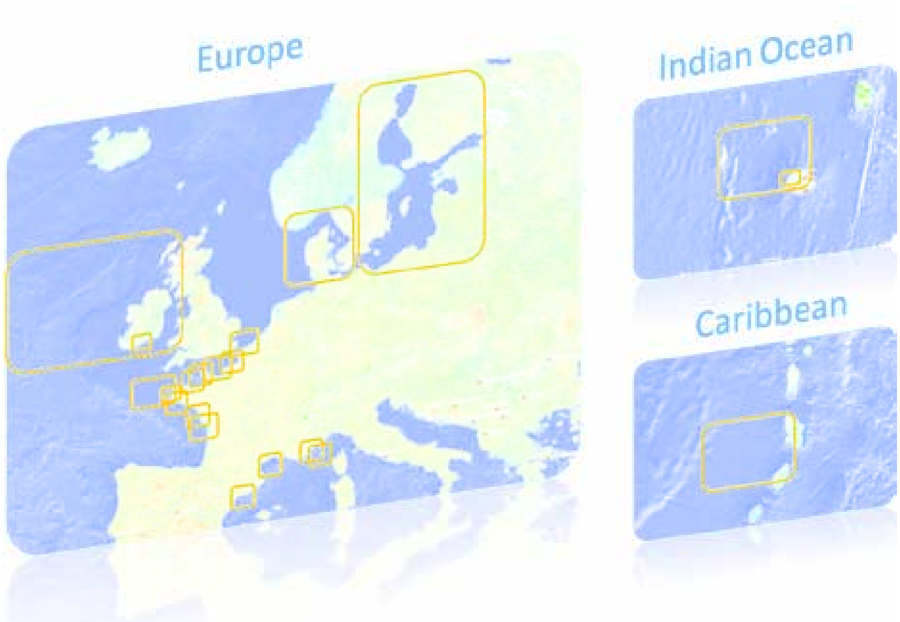


Figure 2.4. Quonops© coverage since 2011.

- Predicting the order of magnitude of potential risks to marine mammals, in order to inform decision-making;
- Assisting in the development of detailed protocols for measurement and monitoring strategies.

2.3.5 *Existing Knowledge Gaps*

2.3.5.1 Sediment properties of the sea floor

The uncertainty regarding the geo-acoustic properties of sediments and their spatial distribution is accounted for by employing a Monté-Carlo approach (details provided in Section 2.3.6), which enables parameters to be varied within a range of uncertainty. This takes into account the sensitivity of the results to these uncertainties. Within an operational framework and in order to reduce the magnitude of these uncertainties, integrating *in situ* measurements (coring, seismic survey and geo-acoustic inversion) would help to adjust the geo-acoustic parameters within the Quonops© platform, and hence allow the effects of the seabed on the estimated noise footprints to be taken into account with greater precision.

2.3.5.2 Existing noise signatures

Some fine details such as the differences in sound output between two ships involved in the same type of activity (e.g. commercial traffic) are not taken into account. Individual vessel or airgun signatures are not known at this stage. An average value of energy introduced is applied for each type of source (eight different types of vessels and airgun as a function of power). To overcome the uncertainty linked to the detailed noise signature of each type of sound source, an interval of confidence is defined for each source and for each one-third octave.

2.3.5.3 Cumulative effects

For conservative purposes, seismic noises are accumulated over the period of survey. The periods of time taken into account are cumulative effective durations. For example, '8 hours' can mean that the noise has been generated 'continuously' for 8 hours but with a given duty cycle that has been taken into consideration. The SELs are therefore cumulative, irrespective of the interruptions that may occur and for which no information was available.

2.3.5.4 Estimation of biological impacts

The impact of human activities on marine life can be assessed over a continuum of levels (NRC, 2005) from individual to population. There is a recognised lack of knowledge and clear need for further study at the population level (NRC, 2005). Given how difficult it is to study living animals in the wild, most of the knowledge on the hearing sensitivity of marine mammals and the impact of sound on their hearing has been acquired through the study of captive individuals (bottlenose dolphin, beluga, porpoise and killer whale) or species that are potentially accessible from the coast (seals). To date, the audiogram (or at least the auditory sensitivity to certain frequencies) of 32 species of marine mammals has been measured (Simard & Leblanc, 2010). The research reported in this study addresses the level of impact on the individual in terms of permanent hearing impairment, temporary hearing impairment and behavioural disturbance (Southall et al., 2007).

2.3.6 Statistical Approach

The stochastic nature of ambient noise is linked to the unpredictable nature of anthropogenic noise sources and, to a much lesser extent, subtle environmental conditions. For example, it is particularly difficult to predict when the next vessel will pass a given position within Irish EEZ waters. The effects of noise on animal species are also of a stochastic nature as only a statistical estimate of the risk incurred due to such noise can be given. In order to overcome this fundamental characteristic, the suggested approach is based on a statistical characterisation of the noise and associated risks.

In practice, the soundscapes produced by Quonops© are compiled using every combination of a set of environmental and anthropogenic situations representative of the study area (Fig. 2.5). The use of a Monté-Carlo approach[13] then helps determine the seasonal statistics of the sound fields and describe the acoustic status of the study area in terms of acoustic level probability and spatial distribution. The 'anthropogenic situation' parameter translates 'frozen' situations of the spatial distribution of the anthropogenic sources generated by existing activities (for the initial state) or by the project (for the project's noise footprint). This approach enables the introduction of the uncertainty associated with a number of input parameters and the capturing of the effect of these uncertainties in the statistics of the soundscapes.

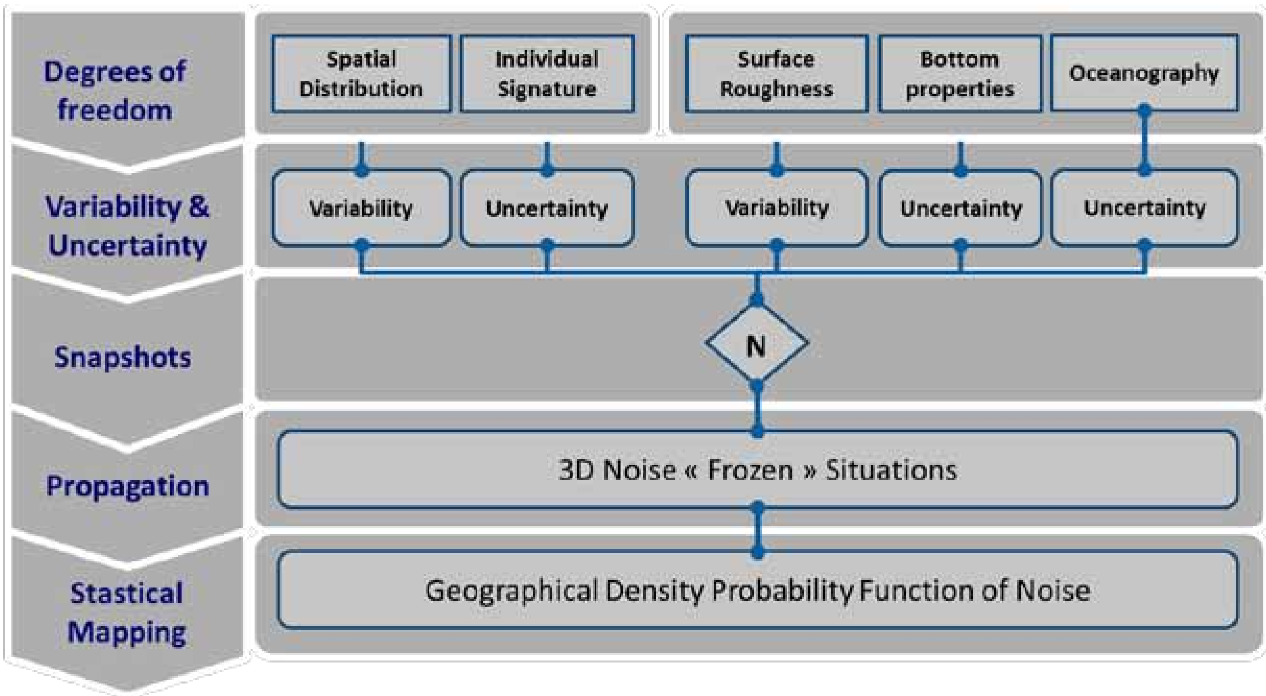


Figure 2.5. Statistical approach based on Monté-Carlo for the soundscapes.

13 The Monté-Carlo method is a numerical method that uses random drawing to calculate a deterministic quantity. It is widely used in finance, earth sciences and life sciences.

3 Data-Mining of Environmental and Anthropogenic Data

Section 3 gives an overview of the environmental and anthropogenic data that have been used to produce the soundscapes. Baseline data used to produce the soundscapes include:

- The physical description of the environment, such as bathymetry, sediment, oceanography and surface waves;
- The description of the human activities, such as shipping activities, and seismic activities between 2000 and 2011.

3.1 Physical Description of the Environment

Since underwater sound waves can propagate over several tens or even hundreds of kilometers, sound sources outside the EEZ are likely to make a significant contribution to the noise inside the EEZ. Therefore, the acoustic study area extends considerably beyond the EEZ perimeter. The data-collection area includes the Western Channel and extends to the French coastline in the south, to the English coastline in the east, and to the coastline of Scotland in the north. Figure 3.1 shows the overall area included in the model domain, the bathymetry used for the model, and the standard division of the domain into cells within two zones of different resolution:

- 1 degree by 1 degree (offshore);
- 0.5 degree by 0.5 degree (shelf and near shore area).

This grid provides the basic unit of resolution for most of the environmental parameters that have been assimilated into the modelling framework.

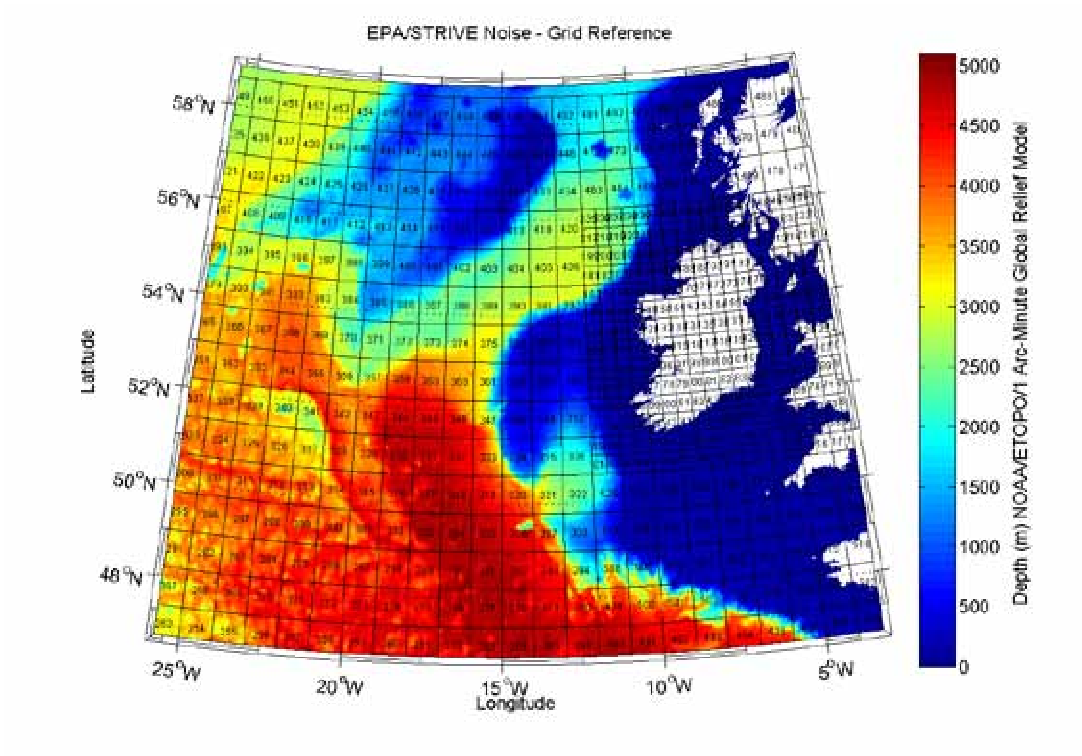


Figure 3.1. Grid for environmental data limits and bathymetry.

3.1.1 *Definition of the Seasons*

Seasons, which were defined based on the seasonal daylight levels and average sea temperatures for the west of Ireland (Bowyer & Ward, 1995; Boelens et al., 1999), are defined as:

- Winter (January to March);
- Spring (April to June);
- Summer (July to September);
- Autumn (October to December).

3.1.2 *Bathymetry*

The pattern of sound propagation in the ocean is heavily influenced by the topography of the ocean floor and the nature of the sediments (Guiesse & Sabathié, 1964). The modelled area was bathymetrically complex, with strong contrasts between the relatively flat coastal shelf area, and large offshore features such as the Rockall Trough, Porcupine Sea-bight and Hatton Bank, all of which exert a significant influence on the resulting propagation patterns. Bathymetry data come from the General Bathymetric Chart of the Oceans (GEBCO) database established under the joint authority of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the International Hydrographic Organization (IHO).

3.1.3 *Sediment Types*

Seabed sediment properties also strongly influence the propagation of sound owing to differences in the acoustic reflectivity associated with each sediment type. Seabed sediment distribution data was sourced from the MESH Atlantic project (www.meshatlantic.eu), which provides the most up-to-date data on the seabed sediment classified according to the EUNIS system. The EUNIS classifications were matched with their equivalents from the APL Laboratory (1994) tabulation based on expert knowledge (Max Kozachenko, CMRC) as shown in Table 3.1, giving a total of eight different sediment types, and the corresponding mean values for the key geo-acoustic properties that were used for the acoustic-propagation modelling. These geo-acoustic properties are described in terms of three main components: (i) density; (ii) compressional speed (celerity); and (iii) sound attenuation. Effectively, this means that the harder the bottom (e.g. rock) the more sound is reflected, whereas softer sediments (sands and muds) tend to trap acoustic energy.

When the information from available broad-scale sediment distribution maps is transformed on the basis of the values contained in Table 3.2, the resulting maps provide the basis for representing and understanding the spatial variability of the three key acoustic properties. Preliminary processing was required in order to aggregate the original sediment classification data, by aggregating it into the standard grid for the whole modelling domain. Each grid cell was ascribed a single sediment type based on the predominant sediment occurring in that cell in terms of area occupied. Original sediment type information was lacking for a proportion of cells in the domain (mainly outside the Irish EEZ area), and these cells were allocated a nominal ‘sand’ classification on the grounds that this sediment type (along with muddy sand and mud) dominated the offshore sediment types in the area for which data was available, and was considered to be a reasonable mid-range compromise. It should be noted that any biases introduced through the use of these assumed values are most likely to affect the outcomes of propagation of sound from seismic exploration outlined in Section 3.4.

Table 3.1. Sediment type and acoustic properties of the Irish substrate.

MESH classification	Sediment type	Density (T/m^3)	Compressional speed (m/s)	Attenuation (dB/l)
Sand	Sand	1.84	1800	0.88
Coarse sediment	Gravel	2.50	2750	0.75
Rock	Rock	2.50	3820	0.75
Mud	Clay	1.22	1583	1.10
Muddy sand	Muddy sand	1.34	1650	0.94
Mixed sediment	Gravelly sandy mud	2.15	1870	0.90
Sandy mud	Sandy mud	1.27	1614	1.02
Macrophyte-dominated sediment	Sandy gravel	2.49	2042	0.93

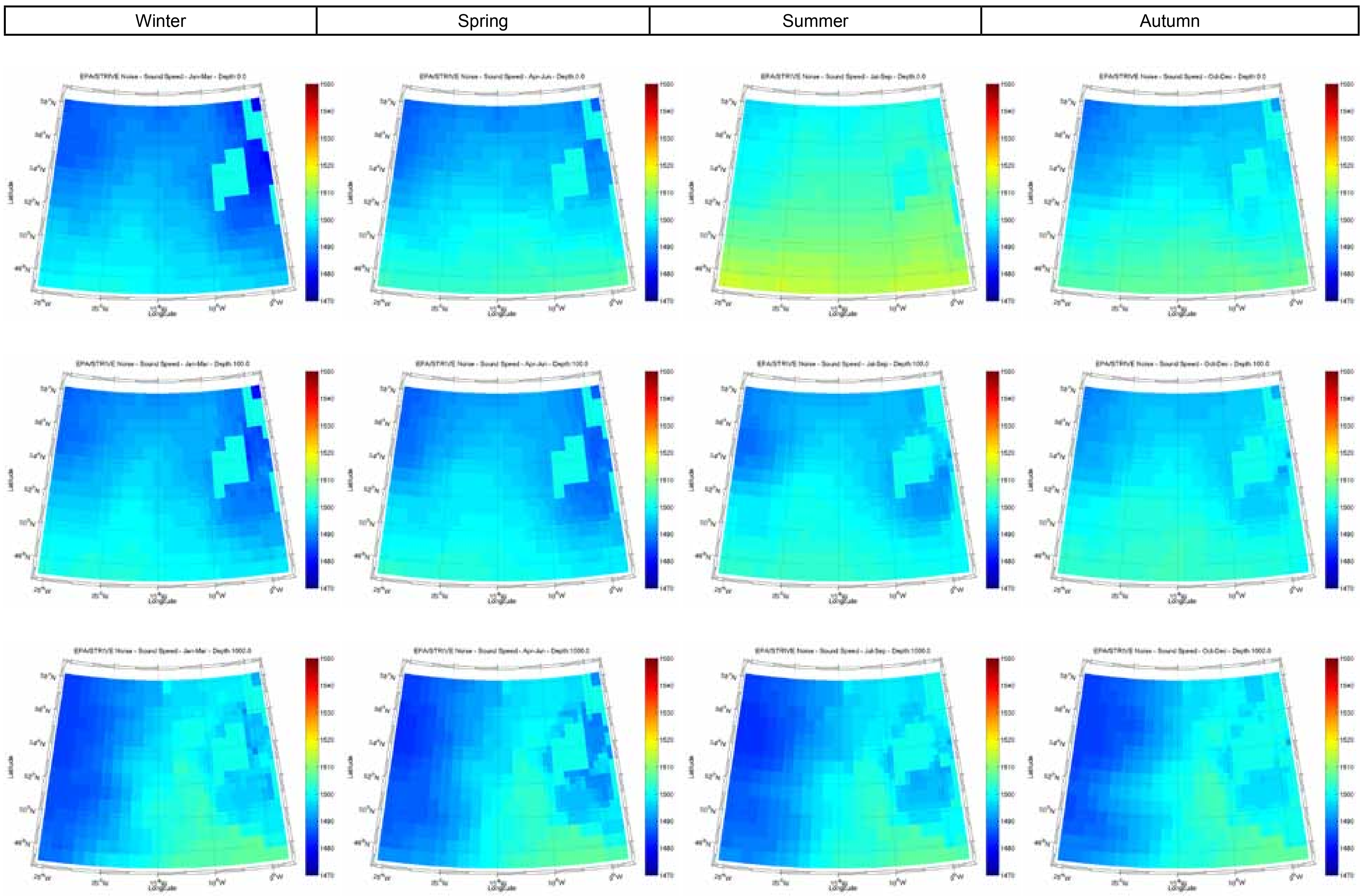


Figure 3.2. Spatial distribution of sound speed for each season. Top row represents sound speed at the surface (0 m), middle row 100 m, and bottom row 1000 m depth. Colour gradient runs from dark blue (slow sound speed) to yellow (fast sound speed).

3.1.4 Oceanography and Sea State

3.1.4.1 Sound speed

Sound propagation in the ocean is heavily influenced by local oceanographic conditions, particularly temperature, depth, and to a lesser extent, salinity. The combination of these three physical parameters determines the speed of sound in sea-water. The spatial and temporal variation in these parameters and particularly in the vertical plane (sea surface to seabed) give rise to gradients in the sound-speed profile which are most significant in the upper 1000 m of the water column, tending towards constant values below this depth. Where acoustic waves travelling through the water column encounter changes in sound speed they will be refracted, bending either toward the surface or towards the seabed. This phenomenon explains the need for the regular collection of sound-speed profiles in order to compute the paths of acoustic pulses used to collect high-resolution bathymetric data, for example by multibeam echosounders. Modelled data for temperature/salinity profiles were obtained from the Marine Institute using the NE Atlantic oceanographic forecast model. This provides modelled data at 2 km grid resolution and provides temperature/salinity data to 40 depth levels spaced proportional to water depth. Figure 3.2 illustrates the seasonal variability of the sound speed across the Irish waters at the surface and at depths of 100 m and 1000 m. Notable features are the seasonal (temporal) variation, which is greatest at the surface and in the upper levels and seasonally stable at depth. The depth-related trend in sound speed can also be seen for each season, and the effects of summer surface heating are clearly discernible with the increased sound speed propagating from the south, which is generally warmer with higher sound speed than northerly areas.

3.1.4.2 Surface waves

The maps shown in Fig. 3.3 give a seasonal view of (water) wave climatology in terms of average wave heights (RMS) for the model domain. Seasonal means and standard deviation were computed from the HIPPOCAS hindcast data (Vijaykumar et al., 2003). Unfortunately, the HIPPOCAS model covers only the

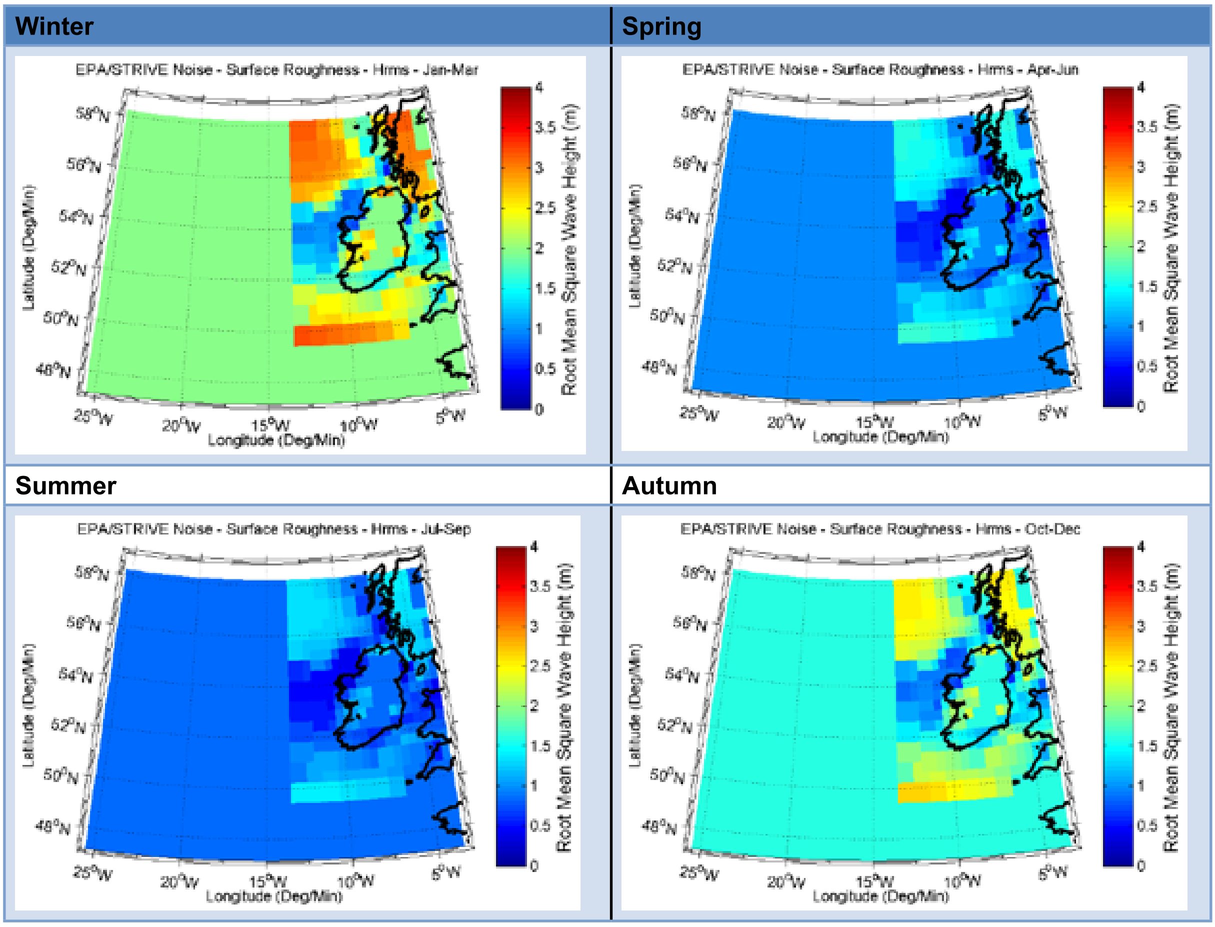


Figure 3.3. Averaged wave heights (RMS) by season derived from the HIPPOCAS hind-cast data.

eastern half of the area of the study. This was overcome by populating the remaining grid cells with the mean value for each season. It is acknowledged that this approach is not ideal and may give rise to localised biases. In general, it is noted that there is a high degree of spatial variability across the area, with hot spots for activity apparent in the south-west and the north-west.

3.1.4.3 Tides and currents

Tidal currents can themselves give rise to environmental noise locally, for example where topographic features generate localised increases in flow and turbulence. The Quonops© prediction system is not configured as a full oceanographic model, and does not reproduce tidal flow. Hence, the effects of tidal currents are neglected in modelling. This simplification is accepted on the basis that the tidally induced effect is very small in terms of sound propagation owing to the vast difference in magnitude between the speed of the sound and the speed of the water. This means effectively that at the EEZ scale the tidally induced spatial variability is within the uncertainty associated with other major variables (e.g. temperature, salinity) that exert significant influences.

3.1.4.4 Natural noise

Wenz (1962) proposed a model for natural noise induced by the surface waves of significant height (Fig. 3.4). Since the Wenz model is general and does not describe the diversity of natural noise levels in Irish waters (both deep and shallow), these curves should be updated based on a dedicated processing of acoustic data acquired in the frame of a noise-monitoring programme.

3.2 Shipping Activities in the Irish EEZ

Shipping generates broadband continuous sound emissions covering infrasonic, audible and ultrasonic frequency bands, from a few tens of Hertz (Hz) to several tens of kHz. A description of shipping activity in the Irish EEZ has been compiled in order to account for sources of anthropogenic noise associated with vessel movements in the study area. The primary source of data used is the Automatic Identification System (AIS). This system is operated as an aid to navigation and maritime safety by enabling ships to be mutually aware in terms of speed, course, ID, current position and several other important attributes. It is mandatory for vessels over 300 gross registered tonnage (GRT),

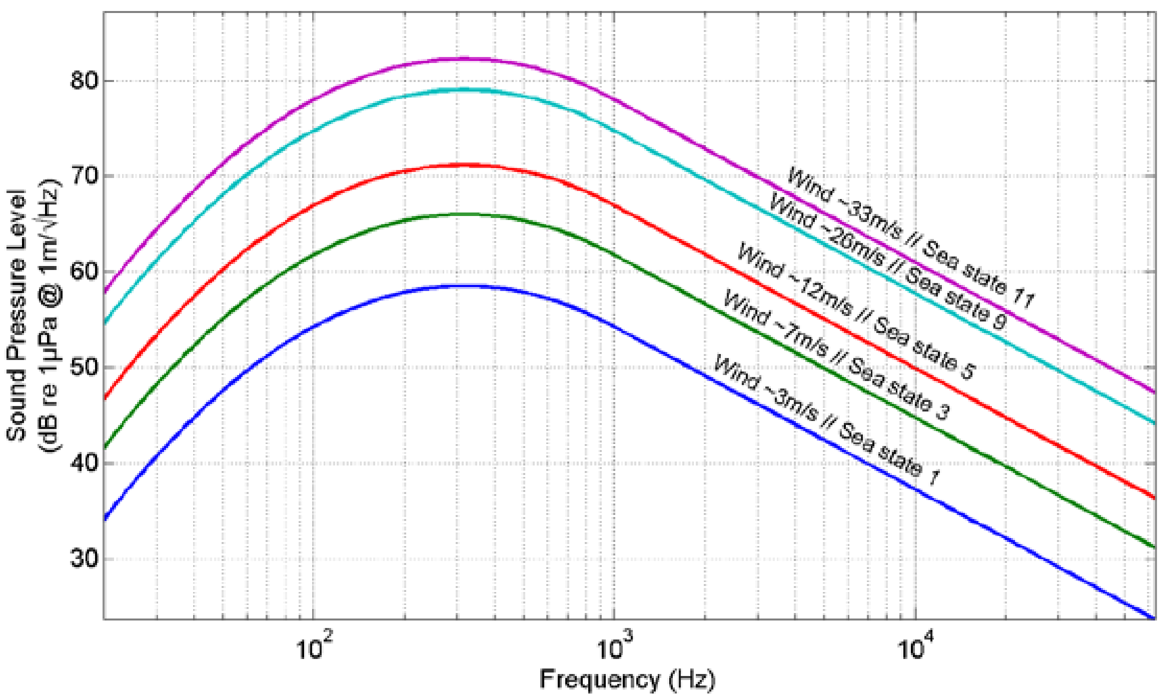


Figure 3.4. Natural underwater noise levels (in dB ref. 1µPa /√Hz) as a function of frequency depending on the sea state and wind speed (m/s). Derived from Wenz (1962).

and recommended (but not compulsory) for smaller vessels such as fishing and leisure craft. Automatic Identification System data were obtained from the Department of Transport, Tourism and Sport and provided by researchers at Galway-Mayo Institute of Technology (GMIT). Whilst this approach provides a reasonable description of shipping activities that is adequate for modelling purposes, it should not be regarded as a fully comprehensive description of all vessel traffic or waterborne activity. The coastal AIS network cannot capture signals from vessels that are far from shore, resulting in offshore vessel movements being underrepresented. Additionally, the contribution from fishing vessels is likely to be underrepresented as an (unknown) proportion may not operate AIS. Since 2012, fishing vessels over 12 m are legally obliged to carry vessel monitoring systems, which would theoretically enable their contribution to be assessed: however, in practice, quantifying this was not considered feasible within the scope of the current study given the degree of complexity involved in resolving potential overlaps between the two sources of information that do not operate on the same update rates.

3.2.1 *Density of Shipping*

In order to represent the spatial and temporal distribution of shipping traffic for noise-modelling purposes, the AIS data were processed to give ship density per km² for each of the four seasons modeled (Fig. 3.5). Processing involved reconstructing vessel tracks based on unique vessel ID (MMSI number), and subsequent resampling of position at a standard 8-hourly time-step (total of 940 separate snapshot situations used throughout the year for subsequent sound-propagation modelling). Missing segments of tracks were reconstructed by extrapolation between recorded locations based on constant speed. For some tracks in the farther offshore area this procedure was complicated by larger data gaps. This is likely to have introduced a certain amount of bias in the shipping density with increasing distance offshore.

The resulting density maps (Fig. 3.5) show very little inter-seasonal variation, which matches with the expected pattern for shipping movements in this region. The most intense vessel activity can be seen to the south-east of the study area, where large numbers of vessels enter and leave the Channel separation zone (about 25% of global maritime traffic). Aside from localised hotspots associated with the major ports, the density of shipping in Irish waters is relatively low in comparison. The AIS data have been analysed in order to assess the potential seasonal variability in predominant shipping type. Fishing and cargo vessels are the predominant vessel classes throughout the year, while pleasure craft activity is much higher in summer. Note there are several spurious individual data points visible to the south-west of the study area. These are artefacts resulting from errors in the positional records.

3.2.2 *Noise Signature of Individual Vessels*

Underwater noise signatures were assigned to each vessel class, defined in terms of sound pressure and frequency. Vessel noise signatures were assigned according to reference values obtained from the literature (Hildebrand, 2009; Wales & Heitmeyer, 2002; Wagstaff, 1973; Ainslie et al., 2009). The average signatures for categories of marine traffic are shown as individual curves in Fig. 3.6. Grey areas around each curve represent the upper and lower boundaries of the Gaussian variance at the 2-sigma[14] level. The model has been programmed to take values at random for each vessel category from anywhere within the variance for that category to enable the introduction of levels of uncertainty.

14 Sigma is the standard deviation, arbitrarily set to 5 dB to introduce uncertainty.

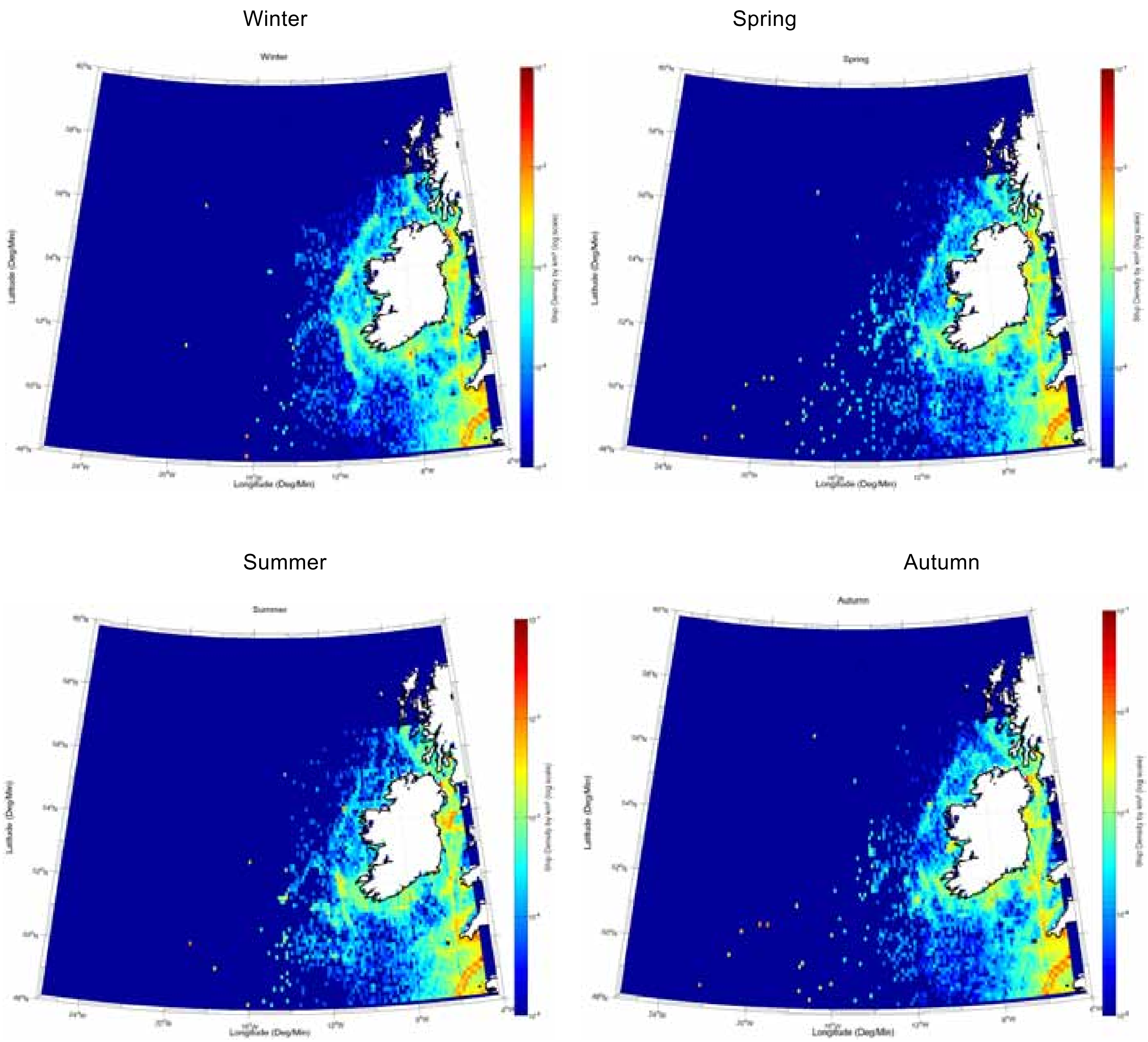


Figure 3.5. Vessel density maps derived from one year of Automatic Identification System (AIS) data. Note that the spring scale is different because the data sample was much smaller.

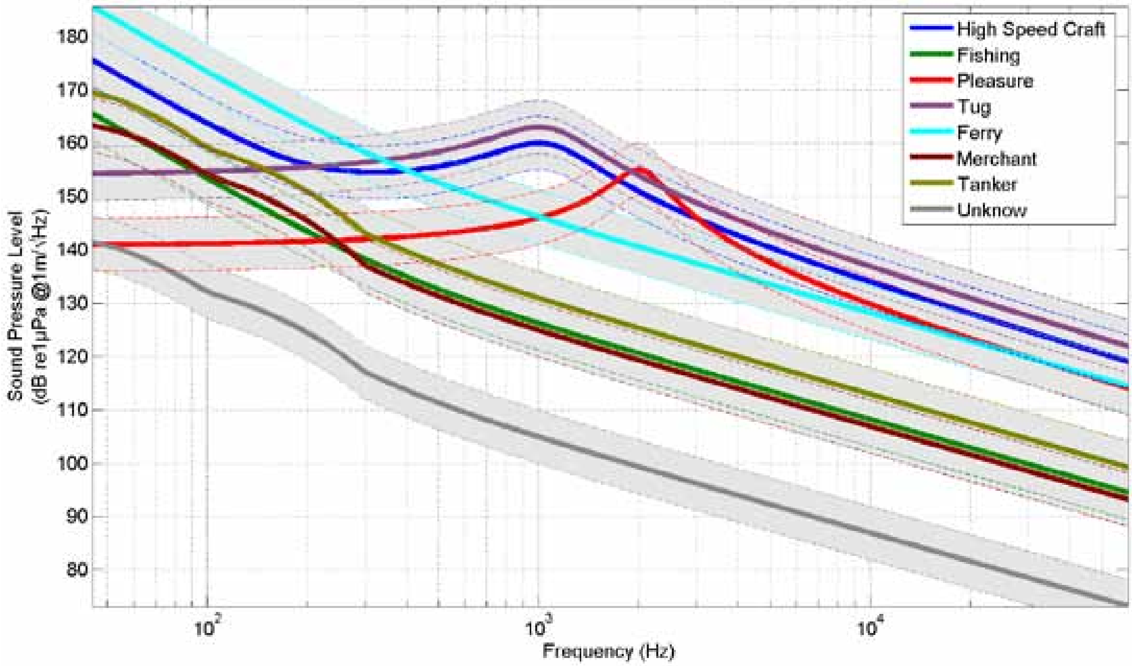


Figure 3.6. Pattern spectra noise levels emitted by ships (in dB ref. 1µPa/√Hz@1m) depending on the frequency and category. The grey areas indicate the variability, uncertainty and level of confidence introduced in the modelling of soundscapes.

3.3 Seismic Activities in the Irish EEZ from 2000 to 2011

The propagation of impulsive anthropogenic sound produced by airguns, typically used for seismic surveying, was determined using a modelling approach. The full list of available parameters used as the basis for defining inputs to the model is given in Table 3.2. The repetition rate for the airgun firing was inferred, since the actual values for this are not typically recorded owing to commercial sensitivity. Because this is an important parameter that governs the amount of energy being delivered to the environment, a value of 20 sec was adopted which is regarded as typical or normal for industry. The repetition rate is a function of mechanical stresses of gun operation, the necessary time of flight in order to achieve the objective (time propagation in the water and the sediment) and the compressor capacity to recharge the airgun. The metadata for describing seismic surveys contains the following fields:

- Type of survey (two dimensional or three dimensional);
- Volume of airgun (related to sound source level – the larger the airgun volume, the louder the 'pulse', measured in cubic inches);
- Source depth (meters);
- Start and end dates of survey;
- Position (longitude, latitude).

Data for inclusion in the sound propagation model were taken from records maintained by the Petroleum Affairs Division (PAD) of the Department of Communications, Energy and Natural Resources (DCENR) via the GMIT assessment of 'pulse-block-days' (Beck et al., 2012.).[15] Between the years 2000 and 2011, a total of 44 seismic surveys were conducted in waters under Irish jurisdiction. Table 3.2 lists the subset of these surveys that were modelled.

15 Available for download at http://www.epa.ie/pubs/reports/research/water/STRIVE_96_web.pdf

Table 3.2. Details of modelled seismic surveys in Irish EEZ, 2000–2011.

Survey index	Type	Start date	Number of cells	Airgun volume (cubic inch*)	Total pulses per cell	Total pulses survey
1	2D	15/05/2000	4	880	6480	25920
2	2D	22/05/2000	9	880	3360	30240
3	2D	31/05/2000	7	880	3703	25920
4	2D	24/07/2000	11	3660	14531	159840
5	2D	28/07/2000	11	2860	3535	38880
6	2D	07/08/2000	15	2860	5472	82080
7	2D	19/07/2003	43	3090	2311	99360
8	2D	15/08/2003	7	3660	4320	30240
9	2D	16/10/2005	77	3660	2749	211680
10	2D	18/07/2006	60	3660	1584	95040
11	2D	11/08/2006	28	3660	1543	43200
12	2D	23/08/2006	13	3660	2326	30240
13	2D	14/10/2006	4	1310	5400	21600
14	2D	11/10/2006	6	1310	18720	112320
15	2D	16/06/2007	88	4258	2258	198720
16	2D	19/07/2007	217	7440**	1015	220320
17	2D	30/04/2008	8	2200	3780	30240
18	2D	01/06/2008	9	150	7680	69120
19	2D	18/06/2008	26	5080**	4320	112320
20	2D	15/08/2009	32	3200	2565	82080
21	3D	13/05/2000	10	3460	30672	306720
22	3D	10/06/2000	17	6180**	10673	181440
23	3D	23/07/2000	10	6160**	43200	432000
24	3D	15/05/2001	10	3460	23760	237600
25	3D	17/05/2001	8	3450	14580	116640
26	3D	11/06/2002	5	3460	31104	155520
27	3D	20/06/2003	9	6920**	26400	237600
28	3D	10/05/2004	6	3090	26640	159840
29	3D	18/06/2006	9	3090	20640	185760
30	3D	22/06/2009	4	3250	27800	151200
31	3D	30/07/2009	1	3250	69120	69120
32	3D	08/08/2010	6	3111	6480	38880
33	3D	01/05/2011	7	3111	8640	60480
34	3D	09/06/2011	18	4240	9120	164160
35	3D	19/07/2011	5	4240	6912	34560

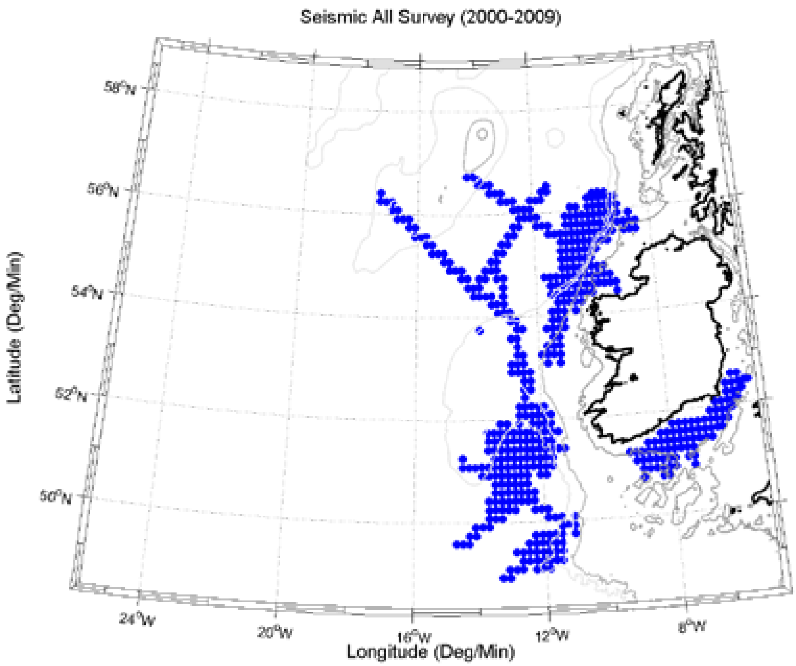
* Airgun volume is typically listed in cubic inches as the recognised industry standard unit. The source reference level and power frequency spectrum associated with different volume airguns used for modelling is discussed in Section 3.3.3 below.

** Airgun paired array used in these surveys – figure represents total airgun volume, however guns are normally fired alternately.

3.3.1 Seismic Activities from 2000 to 2011

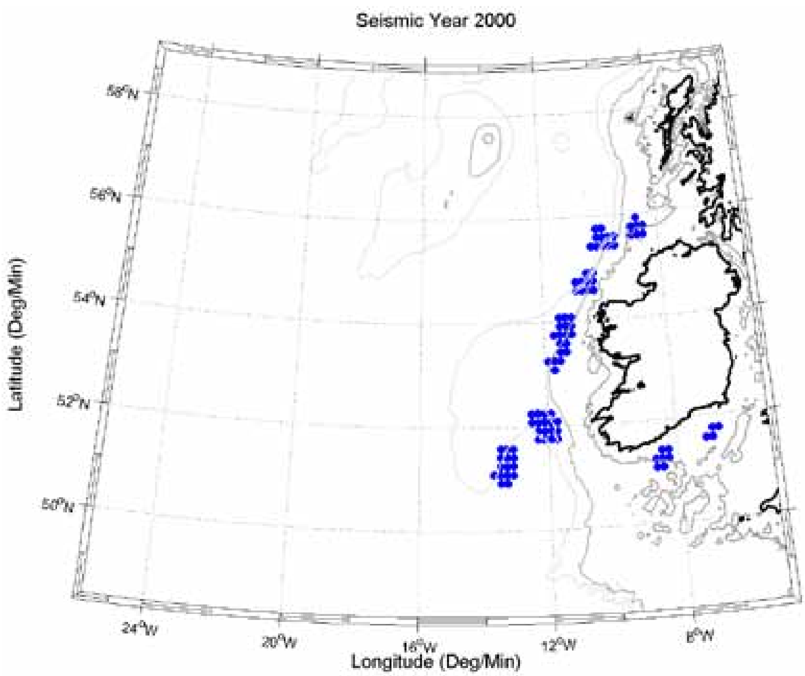
The cumulative distribution of seismic activity over the 11 years (2000–2011) for the model domain in Irish waters is shown in Fig. 3.7 (a). This shows a clear aggregation of activity coinciding with the hydrocarbon plays near the shelf break and continental slope. These features are also commonly associated with current upwelling and increased productivity leading to biological hotspots. Cetacean sightings records suggest that these shelf areas are consequently important for many cetacean species (Ó Cadhla et al., 2004).

Each survey is visualised by plotting a subset of positions, with each position (longitude, latitude) which represent the mean trajectory of the vessel over one or more days. The PAD divides the designated Irish continental shelf into cell blocks of 10’ latitude by 12’ longitude. Seismic survey tracks provided by DCENR were aggregated to these cell blocks for the GMIT assessment of pulse-



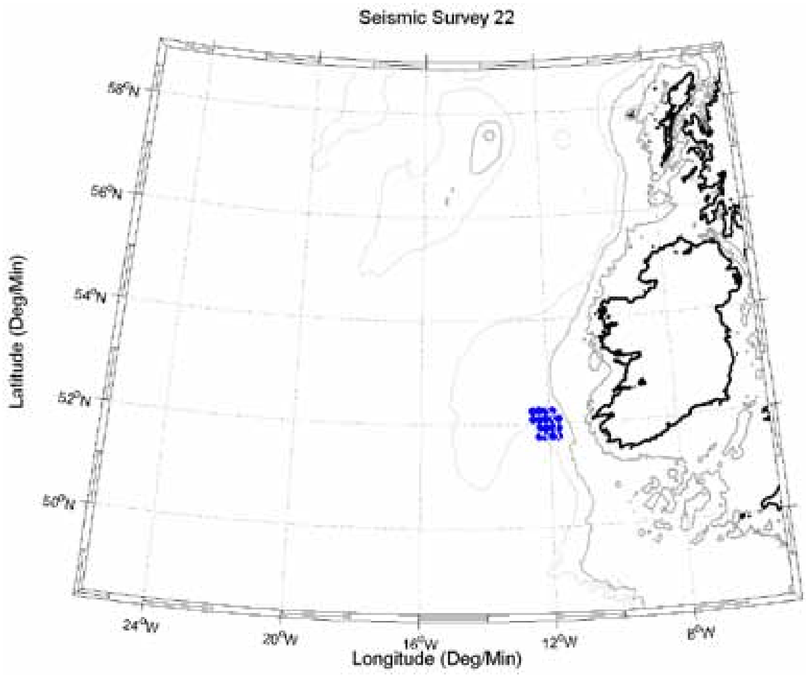
(a)

Figure 3.7 (a). Cumulative distribution of seismic survey activity in Irish waters (2000–2011).



(b)

Figure 3.7 (b). Extract showing the spatial distribution of seismic survey activity for the year 2000.



(c)

Figure 3.7 (c). Extract showing an individual survey (No. 22) from 2000.

block-days. Where surveys spanned more than one cell block, pulse-block-days per block were estimated as the total number of pulse-block-days divided by the total number of blocks for which the survey applied for/ spanned (Beck et al, 2012). Figure 3.7 (b) shows an extract of the spatial distribution of seismic activity for the year 2000. This example has been taken to illustrate and explain subsequent methodological steps.

3.3.2 Spatial Modelling of Seismic Survey Activities

Figure 3.7 (c) shows a single survey (Survey No. 22) during 2000, undertaken by a single seismic vessel, the *Ramform Viking*. DECNR records describe a survey which ran data show a survey ranging from 10 June to 22 July 2010 in the Porcupine Basin with 2 x 3040 cubic inch airguns. By extrapolation, the number of acoustic pulses emitted in each cell has been assumed according to typical operating conditions (guns firing alternately). The estimated mean number of pulses emitted per cell is 10 673 and the estimated total number of pulses during this survey is 181 440. This same rationale was reproduced for each survey listed in Table 3.2 providing a total of 35 individual seismic survey scenarios. The location of airgun activity within the survey is aggregated to cell blocks following the GMIT reporting on pulse-block-days.

The aim of defining these scenarios for past seismic surveys is to produce representative seismic noise footprints for each survey. This is to enable a comparison between the relative dimensions of the 'area of influence' of seismic surveys and the resolution of a given and arbitrary regular grid as proposed in the framework of the MSFD Descriptor 11, Indicator 11.2 (1). This will be explored further in the next section.

3.3.3 Noise Signature of Seismic Survey Activities

As with the continuous sound produced by shipping, averaged curves are required to describe the power frequency spectrum for each of the capacities (in cubic inches) of airgun arrays used during seismic surveys. The graph presented in Figure 3.8 (a) shows the linear nature of the relationship between source level (Log base 10) and airgun capacity (Natural Log) at a frequency of 60 Hz. (Cotton, 2003). Based on this, Figure 3.8 (b) shows the standard reference airgun source level signatures that have been used to provide inputs for modelling (DeRuiter et al., 2006; Madsen et al., 2006; Finneran et al., 2002; Popper et al., 2005). Airguns are designed in order to maximise the downward transmission of energy in order to penetrate the sea floor as much as possible for imaging purposes. It should be noted that the airgun values reported in this report correspond to the energy

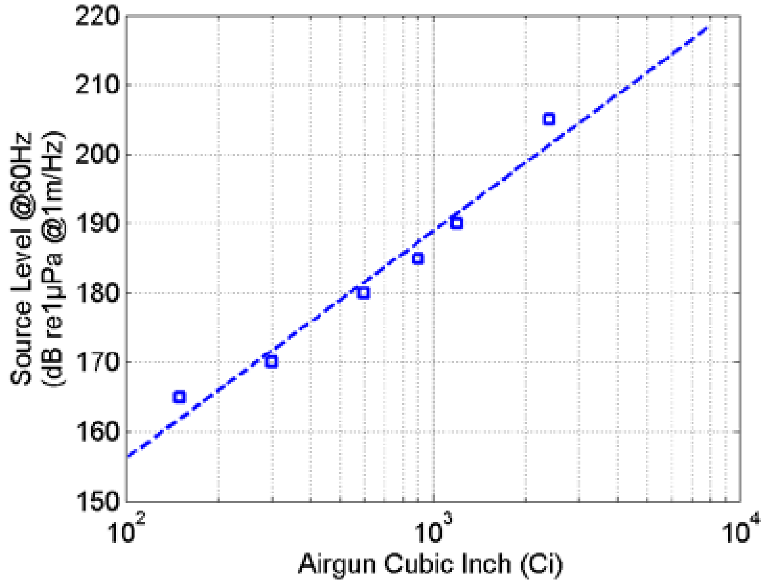


Figure 3.8 (a). Plot showing relationship between source level (Log base 10) and airgun capacity (Natural Log) at a frequency of 60 Hz. (Cotton, 2003).

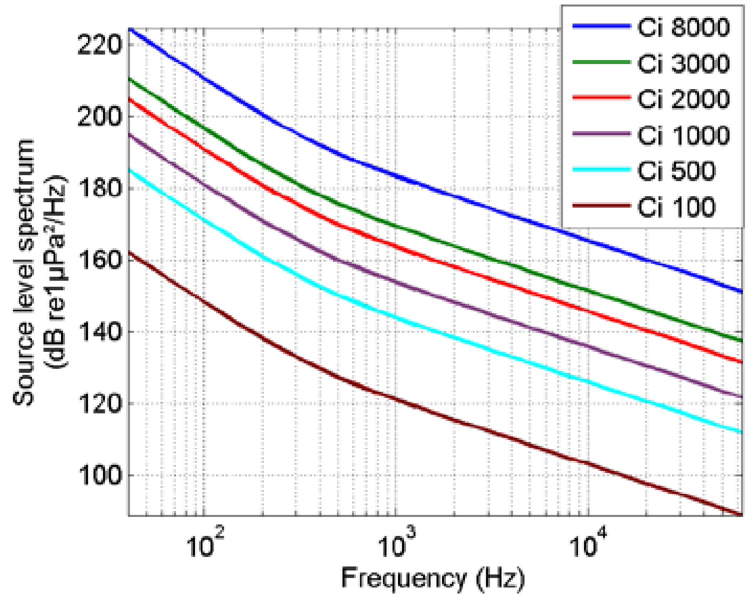


Figure 3.8 (b). Spectrum of source levels as a function of frequency produced by airguns ranging in volume from 100 Cubic Inches (Ci) to 8000 Cubic Inches.

which is effectively propagated away from the airgun near the horizontal plane.

3.3.4 Seismic Survey Effort over the Last Decade

Figure 3.9 shows the total number of seismic pulses estimated per grid cell for each of the 35 surveys, showing an apparent increase in the density of pings with time. The reason for this is unclear: however, it may be associated with misreporting in the number of days during which pulses were made out of the total days per survey. Pulse-block-days were determined according to the data acquisition dates provided in records held by the PAD, where acquisition dates were missing (approximately 7% of the data), dates with seismic data acquisition were assumed for the entire survey duration, which may give an overestimate of pulse-block-days. Since the available survey metadata omit the details which are critical for determining this

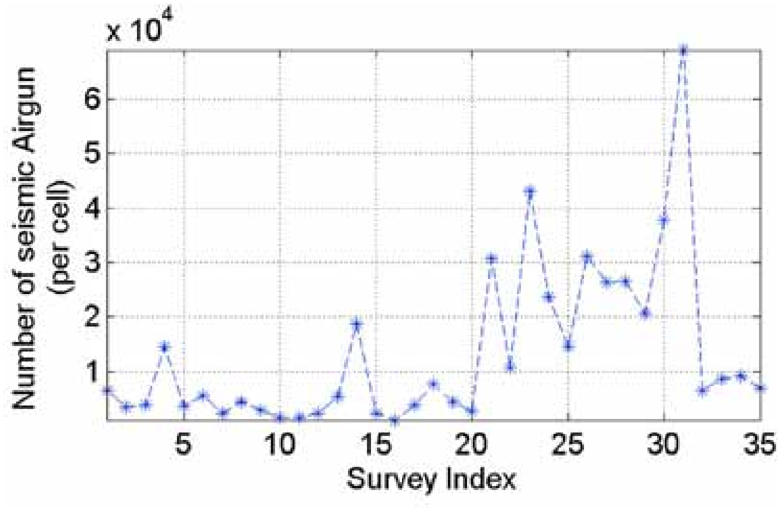


Figure 3.9. Cumulative pulses per cell for each survey 2000–2011.

effect, there is grounds for suggesting that reporting procedures are revised to include accurate information on repetition rates and the exact start, end, and location for each survey day.

3.4 Effect of the Irish Physical Environment on Sound Propagation

Figure 3.10 (a & b) provides a graphic illustration of the effects of the physical environment on sound propagation. It shows a plan view of sound propagating from a nominal source (dark-red area in Fig 3.10 (a)) that is at 10 m depth, and highlights the striking variation in the sound field propagating towards the north (S1) and west (S2), both of which are strongly influenced by the submarine terrain and oceanographic structure. Figure 3.10 (b) provides two cross-sectional views through the water column along each of the two transects. In the case of S1, the source was relatively further from the shelf edge, and hence the bathymetry concentrates the sound energy into the shallow upper layers. Once this has happened, whilst the sound continues to propagate out beyond the shelf edge it remains trapped in a channel above the minimum sound-speed level, ensonifying (filling with sound energy) only the upper layers. Conversely, in the case of S2, the shelf area is much shorter and sound is concentrated down to around 500 m. This is sufficiently deep to allow some of the sound energy to propagate into the lower channel below the sound minimum reflection layer, creating two separate sound transmission channels. These scenarios serve to highlight the importance of taking the sound source location relative to the local bathymetry into account in respect of the potential impact on marine mammals.

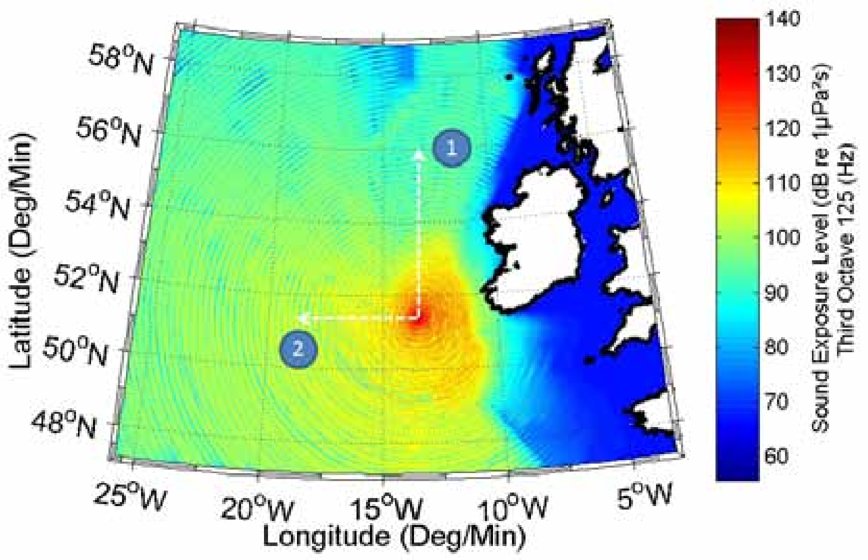


Figure 3.10 (a). Plan view showing location of sound source and the two nominal transects S1 and S2.

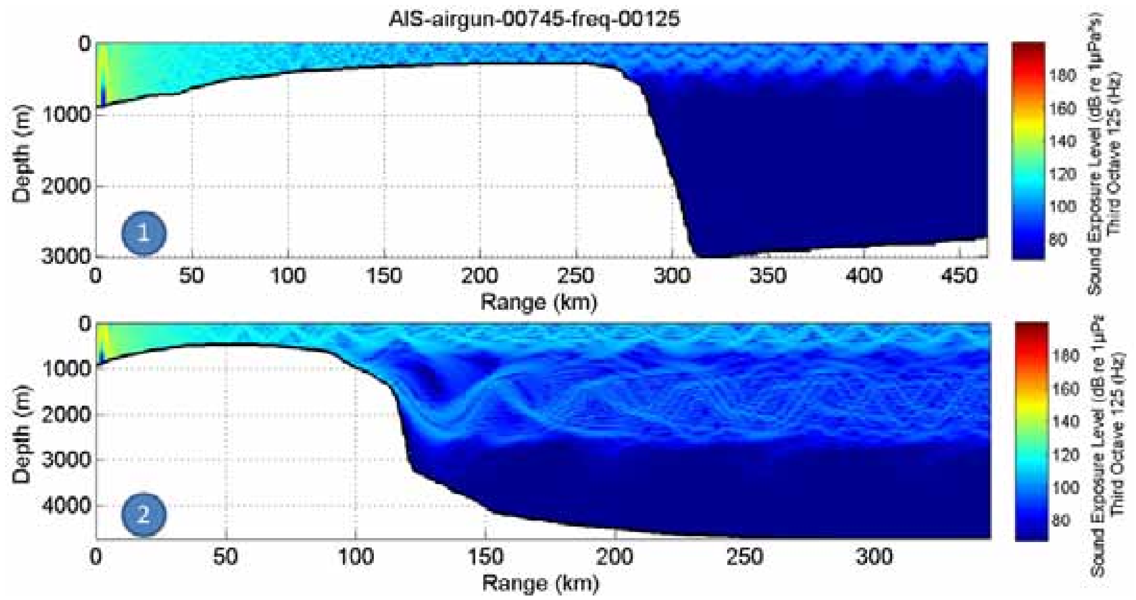


Figure 3.10 (b). Showing the pattern of sound propagation depending on the location of the source relative to the shelf edge. Transect S1 (upper) shows sound propagation confined in a single channel above the sound speed minimum. In transect S2 sound propagates in two channels occupying a large portion of the water column.

4 Shipping Noise in the Irish EEZ

This chapter presents soundscapes for continuous underwater noise linked to shipping activity (MSFD 11.1.1 [European Commission, 2010]). It integrates the various inputs and sub-routines described previously, taking into account the assumptions and limitations that have been outlined. This section also covers calibration and validation of the noise maps using the data from a hydrophone deployed outside Cork Harbour.

4.1 Issues to be Addressed while Producing Noise Maps

There are a number of key physical and environmental factors that must be taken into account in the process of producing shipping noise maps, including:

- The stochastic nature of the distribution of anthropogenic noise sources, such as commercial shipping, ferries, fishing, pleasure activities, etc.;
- The variability of the propagation medium, including tidal changes, sea state variability, etc;
- The uncertainties associated with the complexity and extent of the ocean. For example, sediment type and the sound-speed profile, which is directly dependent on the oceanographic conditions;
- The uncertainties associated with individual anthropogenic noise sources, such as engine status, vessel signature, etc.

4.2 A Monté-Carlo Approach to Soundscapes

Underwater sound propagates very rapidly (approx. 1500 m per second), and over large distances (1000s of kms), and in this case the sound sources (vessels) are mobile. Some sources are more random than others: for example, ferries are more predictable since their movements are based on timetables; commercial shipping is somewhat predictable spatially (shipping routes); and the movement of fishing vessels and leisure craft is highly random. The resulting noise field is stochastic by nature, and to account for uncertainty in the data, a statistical approach based on a Monté-Carlo type analysis (Sawilowsky & Fahoome, 2003) was used. Effectively, random values (from within a certain level of variability from the mean values of each model parameter) are generated and used to produce a 'snapshot' of noise. This procedure is then iterated, giving rise to a number (N) of sound fields equal to the number of runs/iterations. The probability of having a certain noise level for each location (longitude, latitude) on the map is then calculated based on all noise values obtained at that position, as a probability density function (PDF function). The key advantage of this approach is that it provides us with a mechanism with which to capture and estimate the sensitivity of noise maps, ensuring that both the variability and uncertainty associated with input variables, as well as gaps in available knowledge, are factored in.

Figure 4.1 presents three 'snapshots' which show the pattern of sound propagation in Irish waters resulting from shipping. These maps show three seasonal noise scenarios wherein the pattern of shipping varies in terms of vessel types of and their respective locations.

Figure 4.2 illustrates the concepts based on Monté Carlo and PDF functions in graphical form, showing the situation from the perspective of a given location (grid square). A PDF function is produced for each grid square that presents the summary statistics of the ambient sound field based on calculation of percentiles. In this study, N=940 situational noise values at a given location have been modelled. The median value can be calculated from the 940 values of noise at one given location. It corresponds to the level of sound that occurs 50% of the time, also called the 50th percentile; that is, half the time, it will be noisier than this and half the time quieter. A similar approach is adopted for each of the other key percentiles allowing the soundscape to be characterised statistically. By this means, the effects of variability in environmental parameters for each cell have been effectively removed, leaving latitude and longitude as the main variables.

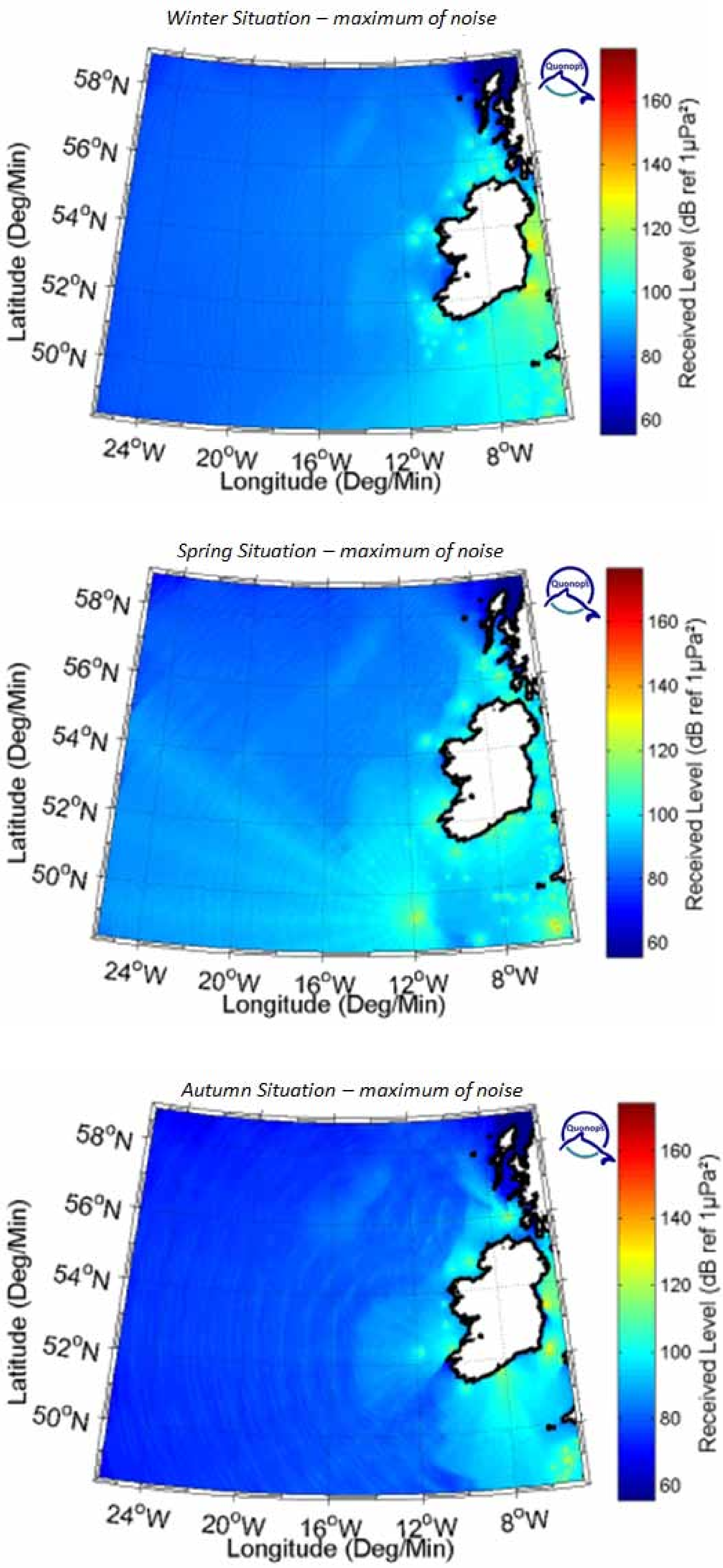


Figure 4.1. Examples of maximum of acoustical snapshot of maritime traffic predicted by Quonops©.

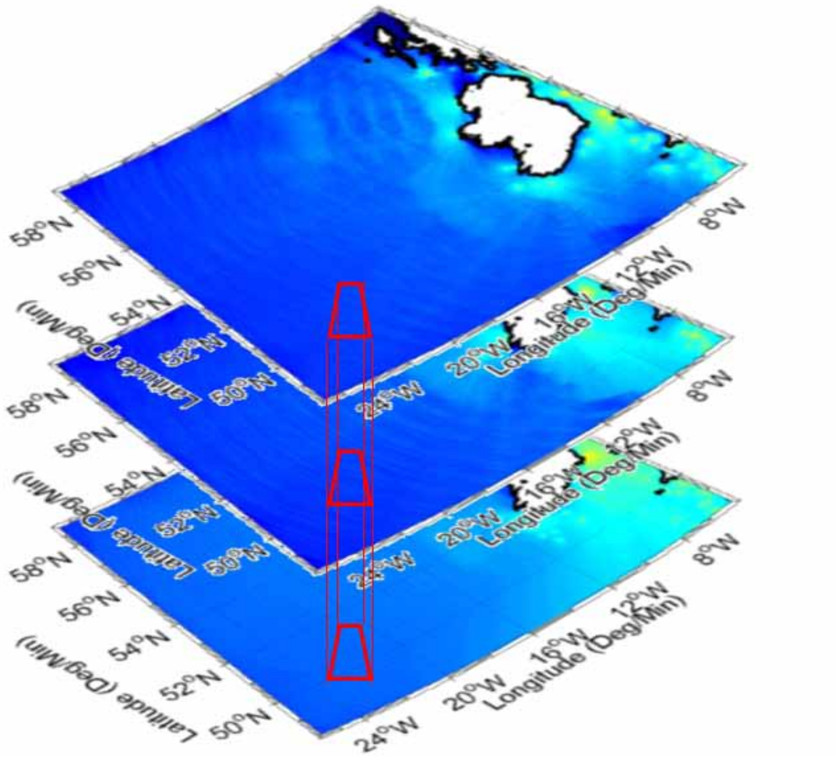


Figure 4.2. Concept of statistical mapping based on a percentile calculation of the N noise situations calculated.

4.3 Shipping Noise Map Calibration

4.3.1 Passive Acoustic Experiment Offshore Cork

The region at the mouth of Cork Harbour is suited to the measurement of underwater noise. This is because in the acoustic context there are representative contributions from multiple forms of vessel traffic (commercial, local, fishing and pleasure craft). Furthermore, qood-quality information on sediment type, oceanographic parameters and supporting AIS data is available. The area is also suitable logistically, with reasonable year-round access via short transits from the nearest landing points at Crosshaven or Cobh.

A high-resolution autonomous underwater sound-recording device was deployed for 16 days outside Cork Harbour (Fig. 4.3) between 10:30:24, 20 April 2012 and 12:14:00, 4 August 2012. The primary aim of this was to accurately characterise the local sound field, and to use this information to ground-truth the predictive sound maps produced by the model. It is important to note that this method provides a means to validate modelled predictions for an area centred on the observation location, which cannot necessarily be extrapolated across the full extent of the model domain. Prior to deployment, a comprehensive assessment was carried out in order to identify key technical and logistical requirements and generate a plan of operations. This included the rationale for adopting the Cork site. A number of ancillary data sets were recorded concomitantly, which included AIS data, visual observations of vessel movements, wind speed and direction, rainfall, tidal flow and wave heights.

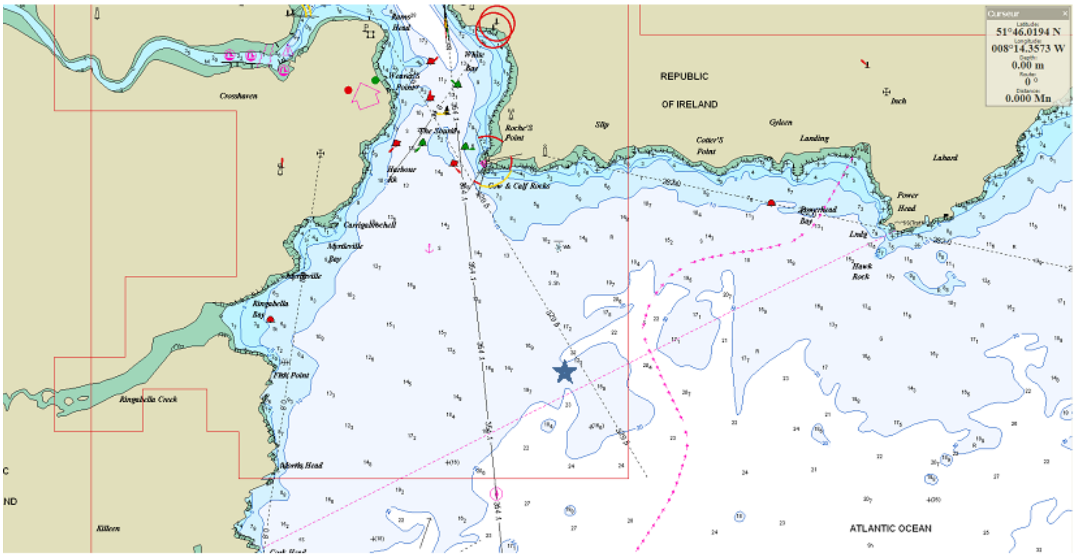


Figure 4.3. Location of experimental measurement off the mouth of Cork Harbour mouth during summer 2012 (blue star).

4.3.2 Acoustic Instrumentation

The autonomous underwater sound-recording device was an RTSYS system (www.rtsys.eu), deployed at 51°45' 40.3 N, 8°14' 37.2 W in 15 m water-depth. The recorder was protected in a trawl-safe frame deployed manually on the seabed (Fig. 4.4). The hydrophone was set at a height of 0.4 m above the seabed, which at this location is predominantly a sandy substrate. The recorder was configured with a duty cycle (the % of time actively recording) of 40% (4 minutes recording followed by 6 minutes off) with a sampling rate of 156.25 kHz.

Figure 4.5 is a sample of the sound record covering 14 days, showing power spectral density in the one-third octave band at 125 Hz (the one-third octave 125 Hz is equal to all the acoustic energy contained between the two frequencies 110 Hz and 140 Hz). Two distinct features are clearly visible in the recording. The thicker blue band towards the bottom represents background noise, which fluctuates mainly in response to environmental variables, the major peaks coinciding with windy events. The less dense and more intensely peaked data in the upper part is representative of anthropogenic sound. Individual peaks correspond to the passage of vessels, whose sound emissions dominate the ambient noise for a short period of time, with levels returning to background between ship-passing events.

Figure 4.4. Trawler-safe cage developed for the deployment of the passive acoustic device.

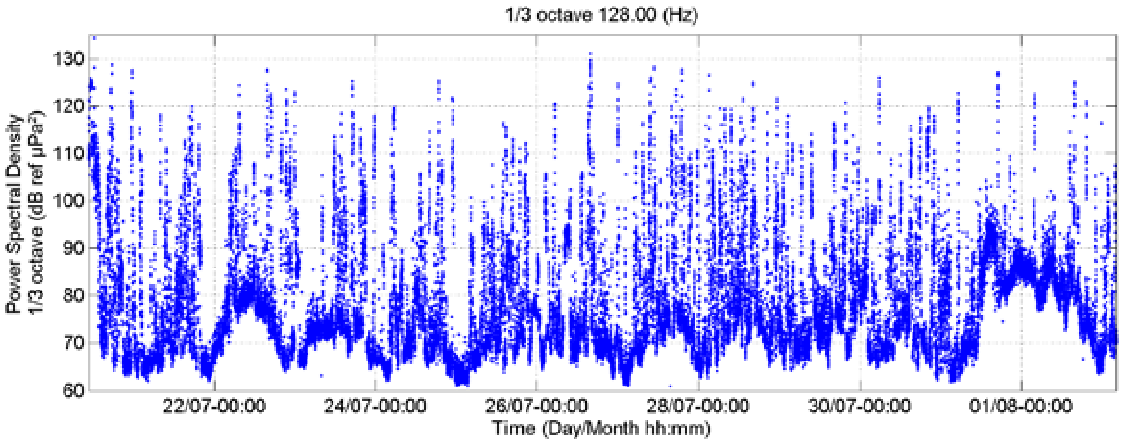


Figure 4.5. Power spectral density of one-third octave 125 Hz during the 14 days of recording.

4.3.3 Processing In Situ *Noise Signal*

Sound data were analysed to produce 'cumulative distribution function' plots – standard curves that provide a characteristic soundscape signature for a given location. These are computed by quantifying the number of individual sound samples that are, for example, above 130 dB ref. 1μPa²; in this case only a few counts, corresponding to a tiny percentage. Thus, the cumulative distribution function plot is built up by iteration across a range of key power values to produce the curve shown in Fig. 4.6. This form of expression provides a powerful representation of an ambient soundscape because it represents a complete statistical integration, including exposure time at particular sound levels. It is relatively straightforward to read off the geometric mean value (78 dB ref. 1μPa²). This represents the sound level that, for a given time period, half of that time the measured level will be greater than this level and half the time the level will be less. This same curve is calculated for each cell in the model for each of the four seasons, providing the basis for direct comparison between modelled output and field observations.

It is important to note that the curve also highlights the distinction between anthropogenic and environmental (background) sound, represented by the right- and left-hand tails of the curve respectively (i.e. above 100 dB ref. 1μPa² 2–3 %, and 60 dB ref. 1μPa², 100%).

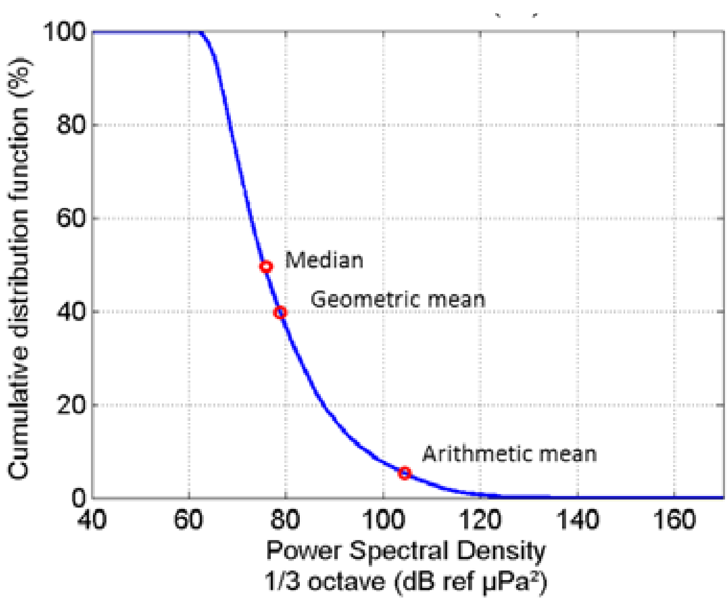


Figure 4.6. Cumulative distribution function for one-third octave 125 Hz during 14 days of acquisition. Characteristic values: median, geometric mean and arithmetic mean.

4.3.4 Determining the Optimum Duty Cycle for Shipping Noise-monitoring and Characterisation

An interesting development to emerge from this part of the study relates to duration of the duty cycle for the sound-recording device (the period of time within a given 10-minute period that the instrument is actively recording the sound it receives). For the Cork experiment a conservative 40% duty cycle (4 minutes recording followed by 6 minutes off) was used. This was considered a good compromise, affording sufficient density of data, whilst also ensuring a minimum autonomous recording period of 2 weeks before draining the available onboard power supply. By artificially removing sound samples from the recording, it was possible to calculate the minimum duty cycle necessary to capture the key statistical characteristics of the Cork soundscape. Using this subtraction technique, it transpires that a 2% duty cycle provides enough data to produce a cumulative frequency plot with the same fundamental statistical characteristics as the 40% cycle. Figure 4.7 illustrates this graphically. It is important to note that these findings are valid for Cork in the summer season, as every location will be different, depending in particular on the local pattern of shipping movements. Nevertheless, this finding clearly has major implications for the design and operation of monitoring systems and protocols. Because the daily data volume can be reduced, real-time data transmission becomes possible, thereby significantly reducing the risk of total loss of data associated with device failure.

4.3.5 Determining *In Situ* Deployment Duration

Further analysis was undertaken to investigate the likely optimum duration of sound observations required to capture a representative soundscape signature. Figure 4.8 shows the individual curves for each day (at the full 40% duty cycle). By adding each day's curve sequentially by eight days the statistical properties of the combined curve have stabilised, demonstrating that adding further days is highly unlikely to add significantly to the picture. This implies that, for Cork, the statistical properties are very sensitive to duration of observation. The overall conclusion that emerges as a consequence of both of these findings is that it is preferable to have a short duty cycle over a longer period than vice-versa. This is an important consideration in the context of capturing the diversity of environmental variables that contribute to the soundscape for a given location. Again, it is noted that these conclusions apply to Cork

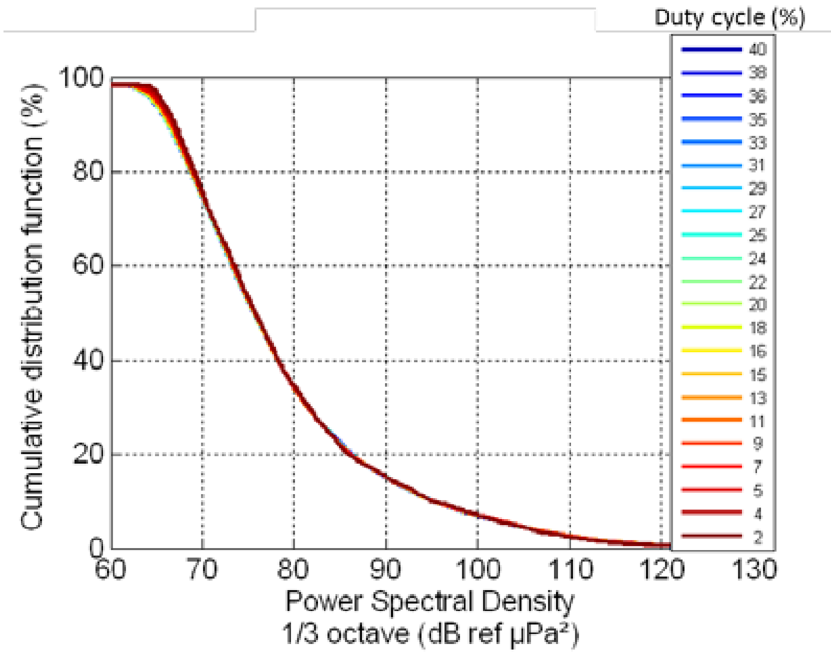


Figure 4.7. Cumulative distribution function versus the artificially degraded duty cycle for the Cork Harbour recordings, July 2012. The statistical distribution of acoustic noise is independent of duty cycle if the duration acquisition is 14 days. The variation of duty cycle has a very weak affect which is only slightly evident in the environmental noise, i.e. lower levels (<70 dB ref. 1μPa²).

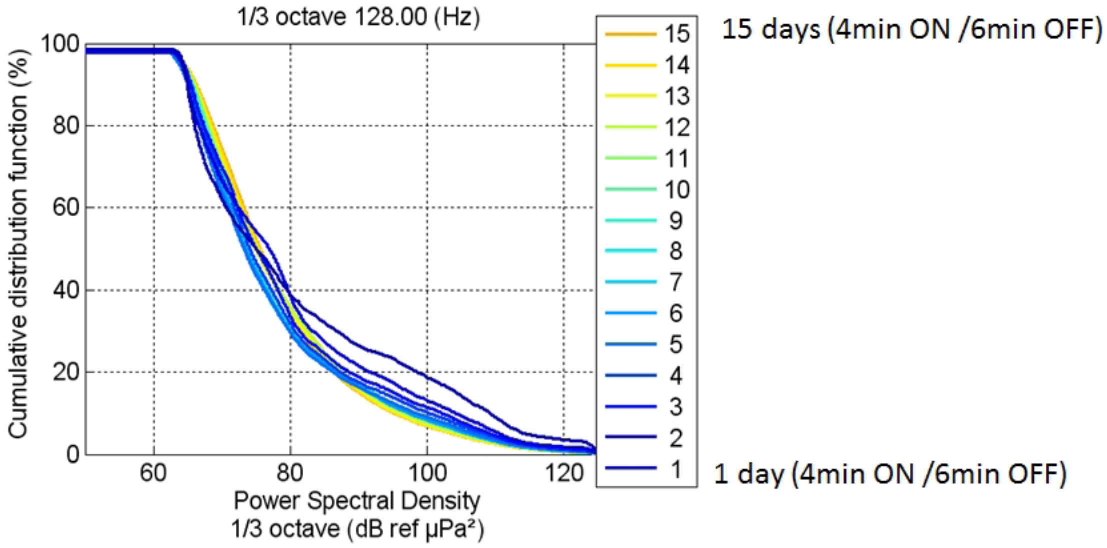


Figure 4.8. Cumulative distribution function versus the duration of experiment. After approximately 8 days' acquisition duration (with duty cycle 40%) the statistical distribution of acoustic noise is stable.

Harbour in summer, and the minimum duration will vary depending on localised conditions. Since shipping movements are a relatively major factor, there may be potential to use AIS maps as an initial reference in determining broad estimates for minimum recording duration.

4.3.6 Statistical Calibration of Soundscapes

This section explains the statistical procedures used to check the calibration of the Quonops® model based on inter-comparison between modelled outputs and field records. Figure 4.9 shows the cumulative frequency curve computed for data recorded at the Cork hydrophone (blue curve), superimposed upon the modelled output for the same location (red curve). In general, there is very good agreement between the two curves. The minor divergence between the curves towards the lower end of the power spectrum (environmental contribution) can be attributed to the fact that the modelling was undertaken using a fixed sea state. In the upper part of the power spectrum (anthropogenic contribution) the match is much closer.

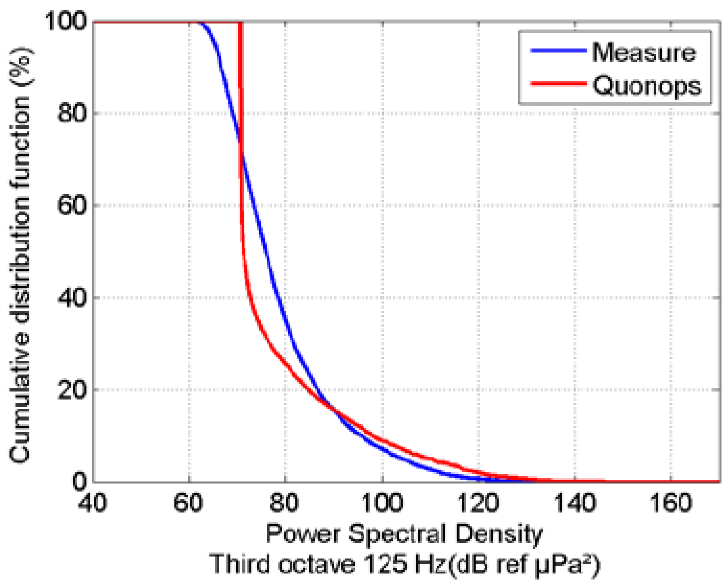


Figure 4.9. Comparison of cumulative distribution function of acoustic noise between measurement and prediction.

The standard calibration procedure for modelling is to iteratively apply small offsets to environmental variables (degrees of freedom), in order to obtain a close match with field observations. In this case, the match was accepted at first pass, and the iterative matching procedure was not required.

4.4 Seasonal Maps of Shipping in the Irish EEZ

The following section presents a selection of the ambient seasonal noise maps that have been produced for Irish waters based on the one-third octave at 125 Hz for each of the main percentiles. Explanatory notes and comments are provided in order to assist interpretation and highlight features of interest. The soundscapes presented are:

- Seasonal soundscapes representative of individual seasons; and
- Statistical soundscapes representative of a given level of probability or percentile.

The noise value at a given latitude/longitude should be interpreted as the probability of measuring a level higher than the displayed level. In other words, for the percentile 1% maps, this means that, for any given location in the grid, there is a 1% probability of encountering noise louder than the value indicated by the colour scale, and so on for the other percentiles. This probability is estimated based on the spatial and temporal fluctuation of the environment (oceanography, sediment and surface wave height), the spatial variability of the shipping activities, and includes the uncertainties associated with gaps in knowledge for sediment and individual vessel noise signature.

4.4.1 Seasonal Maps in the 125Hz One-third Octave

4.4.1.1 Percentile 1%

Figure 4.10 presents the noise maps occurring rarely (1% of the time). In coastal areas, where shipping activities are present, these noise levels are always anthropogenic. These soundscapes correspond to the maximum noise levels predicted at each location

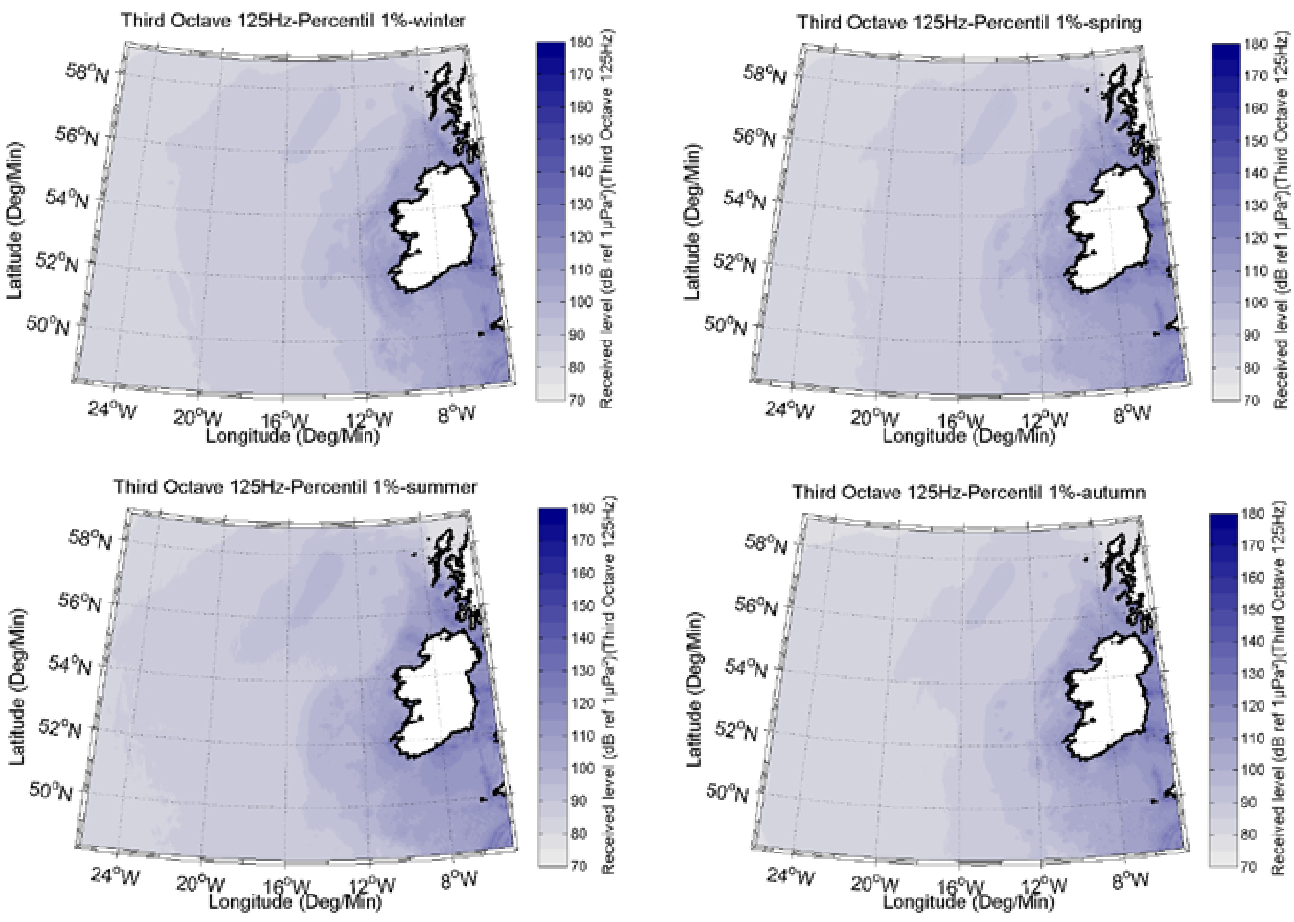


Figure 4.10. Statistical ambient noise distribution for each season at the 1% percentile

independently, so this does not infer that these maximum levels are occurring at the same time.

4.4.1.2 Percentile 10%

Figure 4.11 shows the 10% situation, which represents the minimum level of noise that can be expected to occur 10% of time. This is generally representative of shipping noise. There are some areas of increased noise visible to the north-west of the study area that coincides with a resurgence of sound over the Rockall Bank. In theory at least, this suggests the potential suitability of the Rockall Bank as a location for monitoring trends in shipping noise owing to the capacity to capture the signature of the maritime traffic off the west coast.

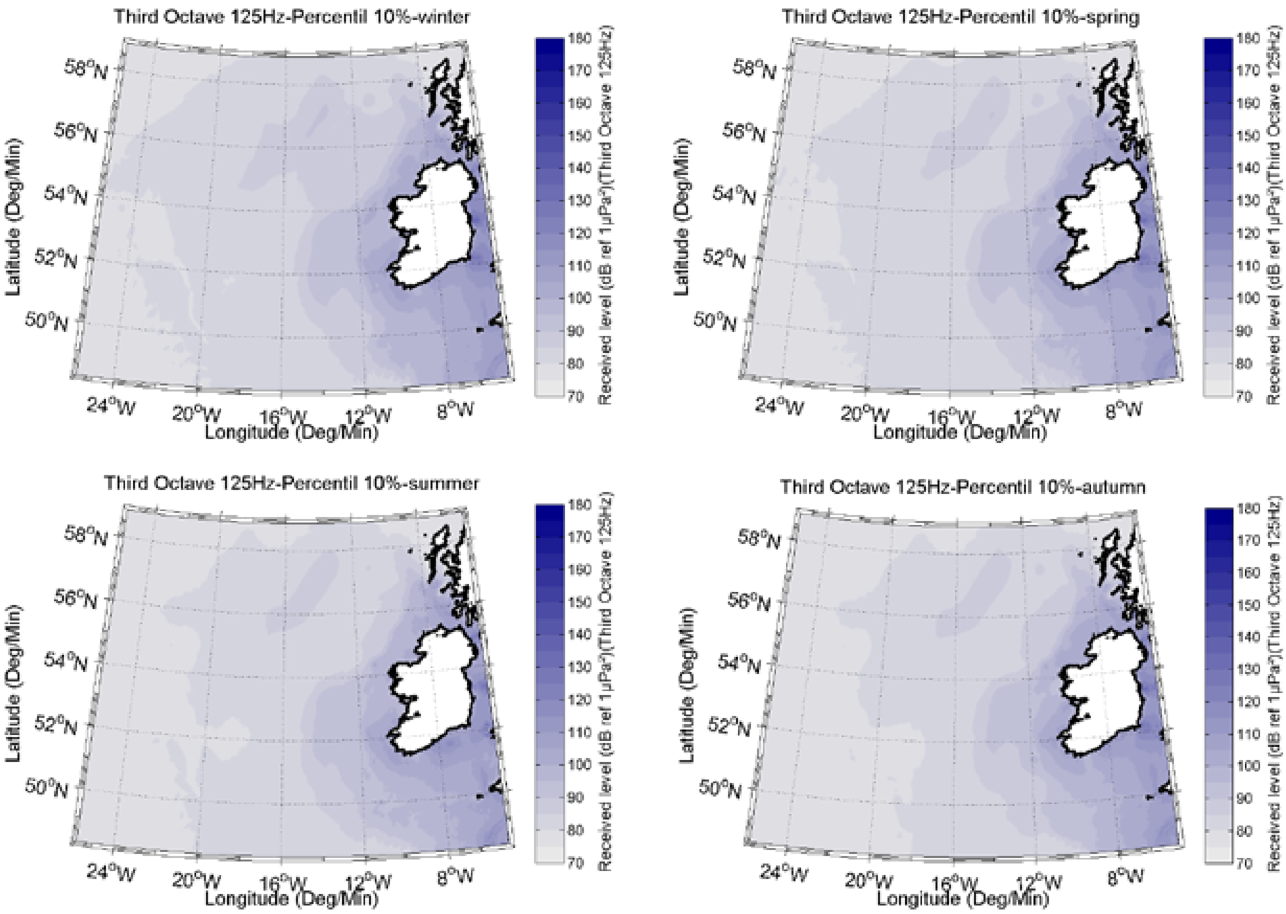


Figure 4.11. Statistical ambient noise for each season for 10% percentile.

4.4.1.3 Median soundscapes of shipping noise in Irish waters

Figure 4.12 represents the situation at the 50th percentile. The maps represent the distribution of sound originating from a blend of contributions from both environmental and anthropogenic sources.

4.4.1.4 Percentile 90%

Figure 4.13 shows the 90th percentile (the sound level is likely to be higher than this 90% of the time), which mainly describes the distribution of environmental noise resulting from waves as the primary contributor. The relatively high values in the Irish Sea and the south coast can be attributed to the effect of bathymetry, which tends to concentrate sound in shallower water.

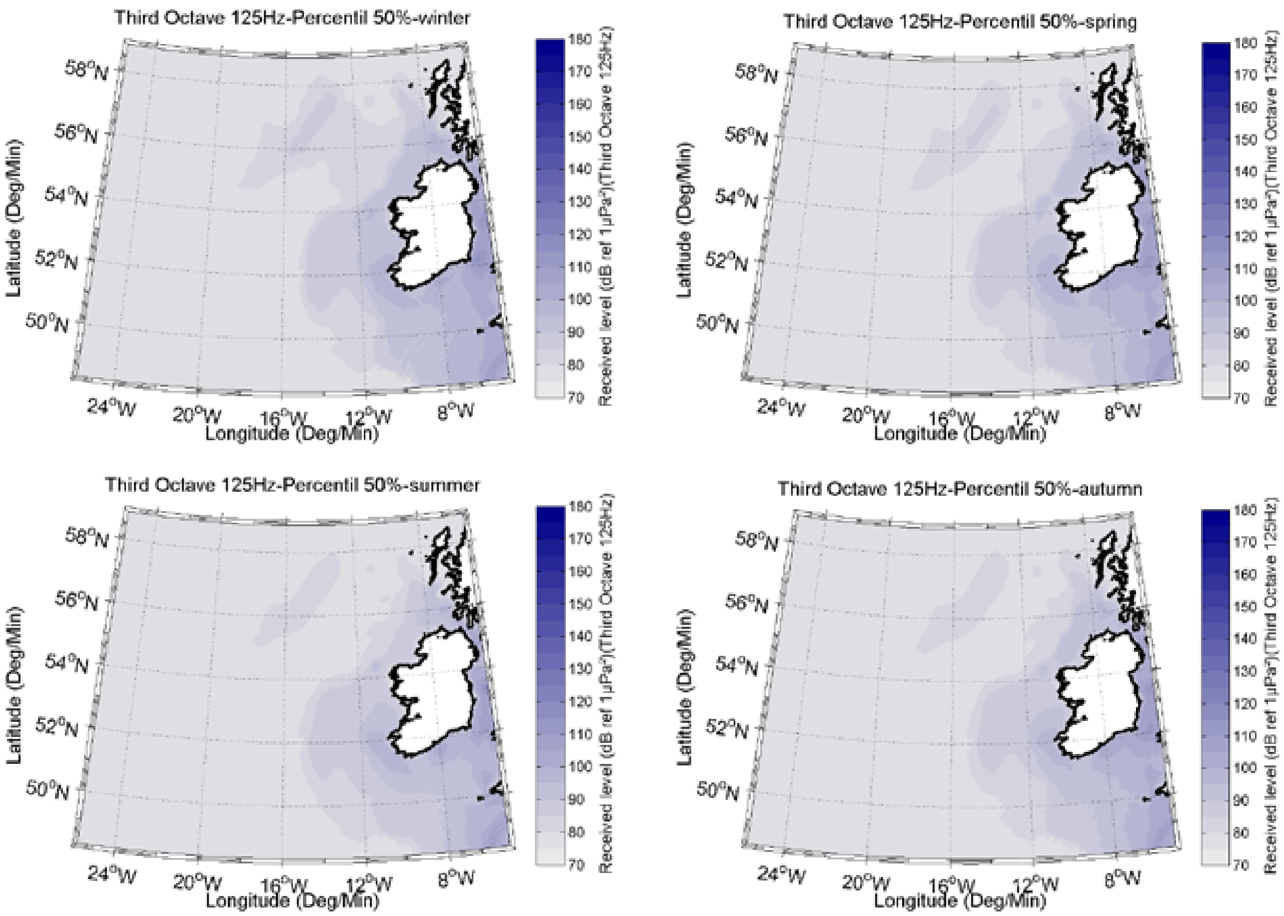


Figure 4.12. Statistical ambient noise for each season for percentile 50%.

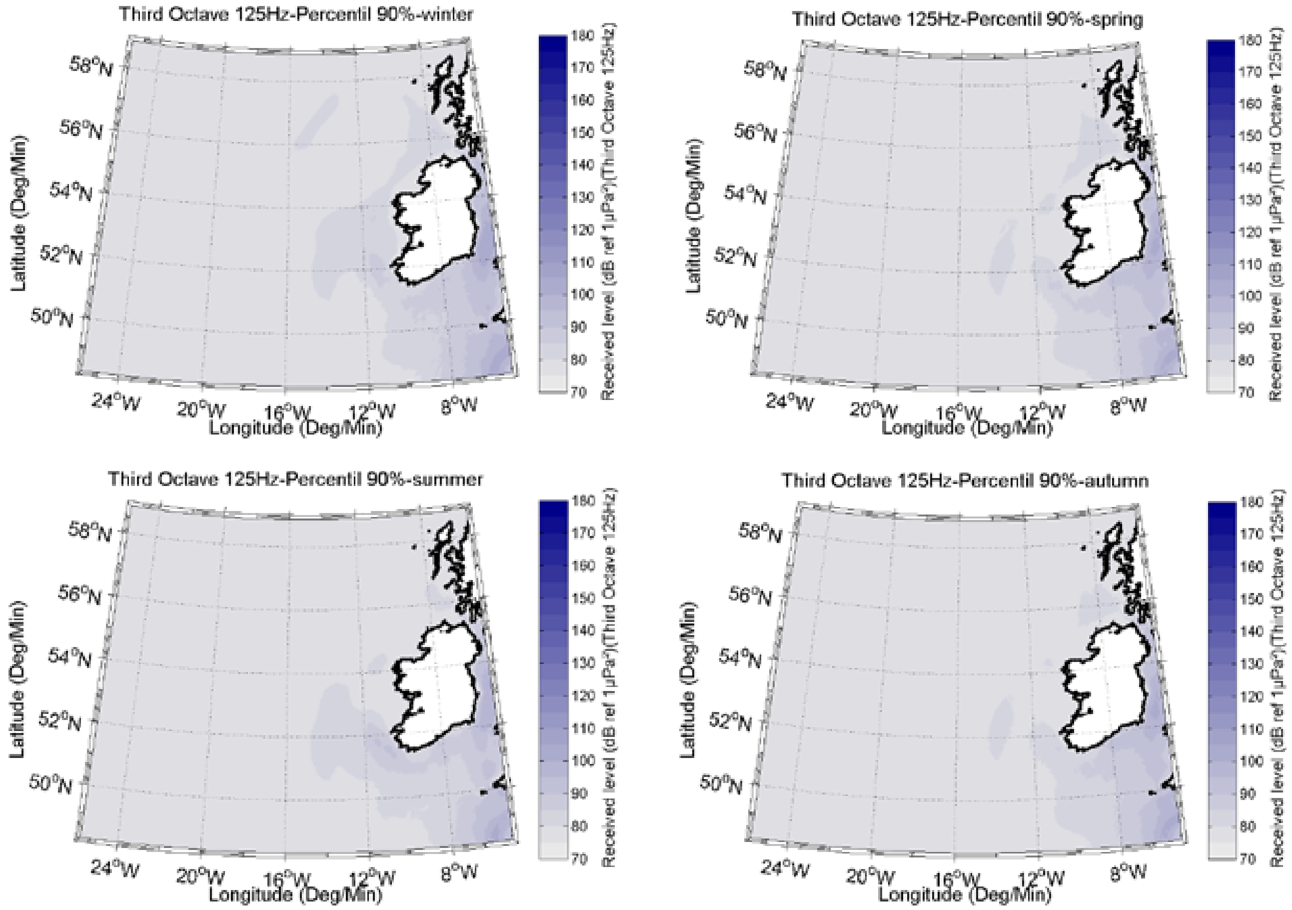


Figure 4.13. Statistical ambient noise for each season for percentile 90%.

5 Impulsive Noise from Seismic Survey Activities in the Irish EEZ

This section covers the treatment of impulsive noise in the Irish EEZ, the main aspects of which are:

- The variability of noise levels and distribution throughout the Irish EEZ, and the influence of bathymetric features;
- The perceived footprint of seismic survey activities, linking physical processes to what is received by (sensitive) receptor species.

5.1 Issues Addressed

The following text concerning MSFD Indicator 11.1.1 is quoted directly from the MSFD (European Commission, 2010):

> 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 Sound Exposure Level (in dB ref. 1μPa^2 .s) or as peak sound pressure level (in dB re 1Pa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1).

The EU Technical Sub-committee on Marine Noise (TSG Noise) has advised extensively on the reporting of impulsive sound in terms of 'pulse-block-days' in the context of Indicator 11.1.1. (Dekeling et al., 2013; Van der Graaf et al., 2012; Tasker et al., 2010). Two key issues are noted in this discussion. The first concerns the dimensions of the grid that should be used for such reporting. Currently, this is based on a rule of thumb agreement mainly influenced by the practical requirements of north-eastern European countries, which have predominantly shallow-water EEZ territories with uniform terrain – making the definition of grids relatively straightforward. However, Ireland and the UK have much more variable underwater terrain which has important consequences in terms of sound propagation (and hence the selection of appropriate grid sizes). Secondly, the cumulative effect of impulsive noise is not addressed in the current 'pulse-block-days' concept (Southall et al., 2007). While it is clear that the 'pulse-block-days' approach has the advantage of being simple to implement, important trade-offs need to be considered. This section attempts to address the pertinence of the 'pulse-block-days' indicator in relation to marine animals whilst taking into account the cumulative impact.

5.2 Definition of Noise Footprint

The 'acoustic source signature' is the noise level generated by a source of noise. The acoustic source signature therefore only depends on the characteristics of the source itself, such as, for a seismic source, the volume of the airgun. The sound source is then transmitted (depth, speed, repetition rate, etc.) into an environment (temperature, salinity, bathymetry, surface roughness, etc.) within the context of anthropogenic (vicinity of a shipping lane or an offshore wind farm, harbour, etc.) noise. The volume of water where the sound source modifies the existing ambient noise such that the sound source will not be masked by other sources of noise is the 'noise footprint'. This is where the influence of the sound source on the physical and biological environment occurs. More specifically, the noise footprint can be linked to its influence on the biological environment, or 'perceived noise footprint', where noise falls within the frequency band of perception of a given species potentially present in the area.

For this study, it is proposed to use the statistical definition of ambient noise to derive the noise footprint of a seismic survey. This is considered to be the area where the noise produced by one pulse is above the median (50th percentile – see Section 3) of existing noise not related to seismic activity. The 'sound exposure level' (SEL) is the mean sound level in 1 second, and therefore the SEL at source (used for modelling purposes) is much lower than the actual peak-peak level (bearing in mind that a single pulse may have a duration of approximately 100 milliseconds followed by 900 milliseconds of silence, which effectively brings down the mean level when averaged across a full second). The term SEL is used consistently with specific meaning throughout the remainder of this report.

5.3 Variability of Impulsive Noise Footprints in Ireland

The following sequences of figures (Figs 5.1–5.3) illustrate variability in seismic footprints due to location (i.e. relative to the shelf edge) and how focused the survey is spatially. Surveys covering a large area result in greater variability because of patterns of variability in survey vessel location, bathymetry and bottom sediment. In general, the footprint from seismic surveys tends to be much larger in deep water where the ambient sound field is relatively quiet.

The effect of variation in the location of the source on the footprint produced by a single pulse is shown for Survey No. 6 in August 2000 (Fig. 5.1). In total this survey covered 15 model cells, and the noise footprint resulting from a single pulse in each of 4 individual cells for illustrative purposes. This shows clearly the large impact on the extent of the noise footprint which can follow from a relatively small horizontal shift in position of the source (refer to Fig. 3.10 above). In this case, the dramatic variations in noise footprint are driven by the proximity of steep slopes in the underwater terrain, which act to trap sound in the deeper water. The extent of the apparent sound footprint is limited in the easterly direction by the bathymetry in this way, but also because of the relative increase in ambient noise caused by the greater amount of shipping noise in this area.

The smaller footprint generated by Survey No. 34 (Fig. 5.2) is due to the survey being in shallow water where a large portion of the sound is absorbed by the seabed, and because the ambient sound field is much higher. The survey was carried out over 18 cells, and 4 of these are shown here for illustrative purposes to illustrate the variability in footprint caused by survey location.

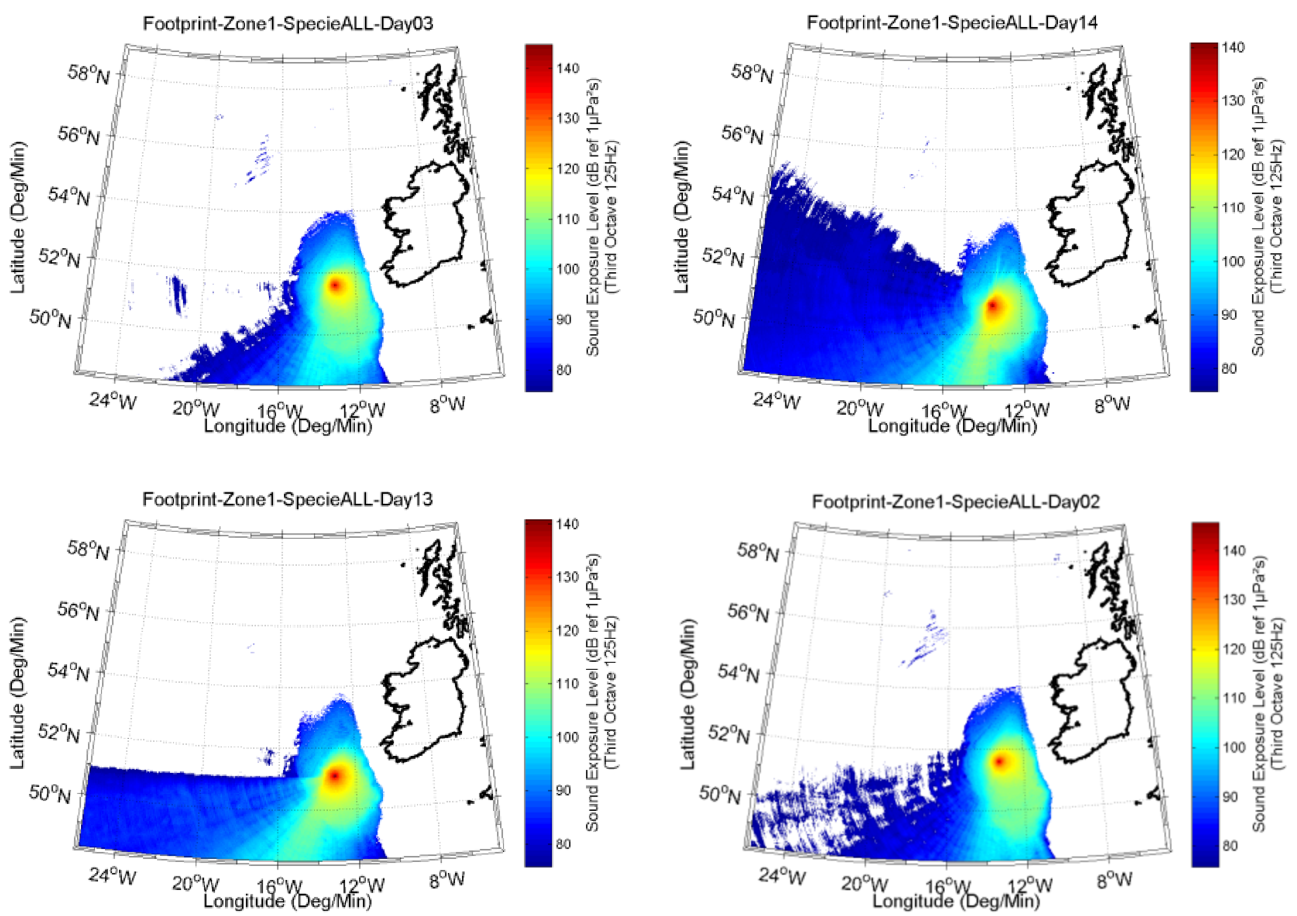


Figure 5.1. Seismic footprint for 4 of the 15 cells covered during Survey No. 6 (2000/08/07–2000/08/26).

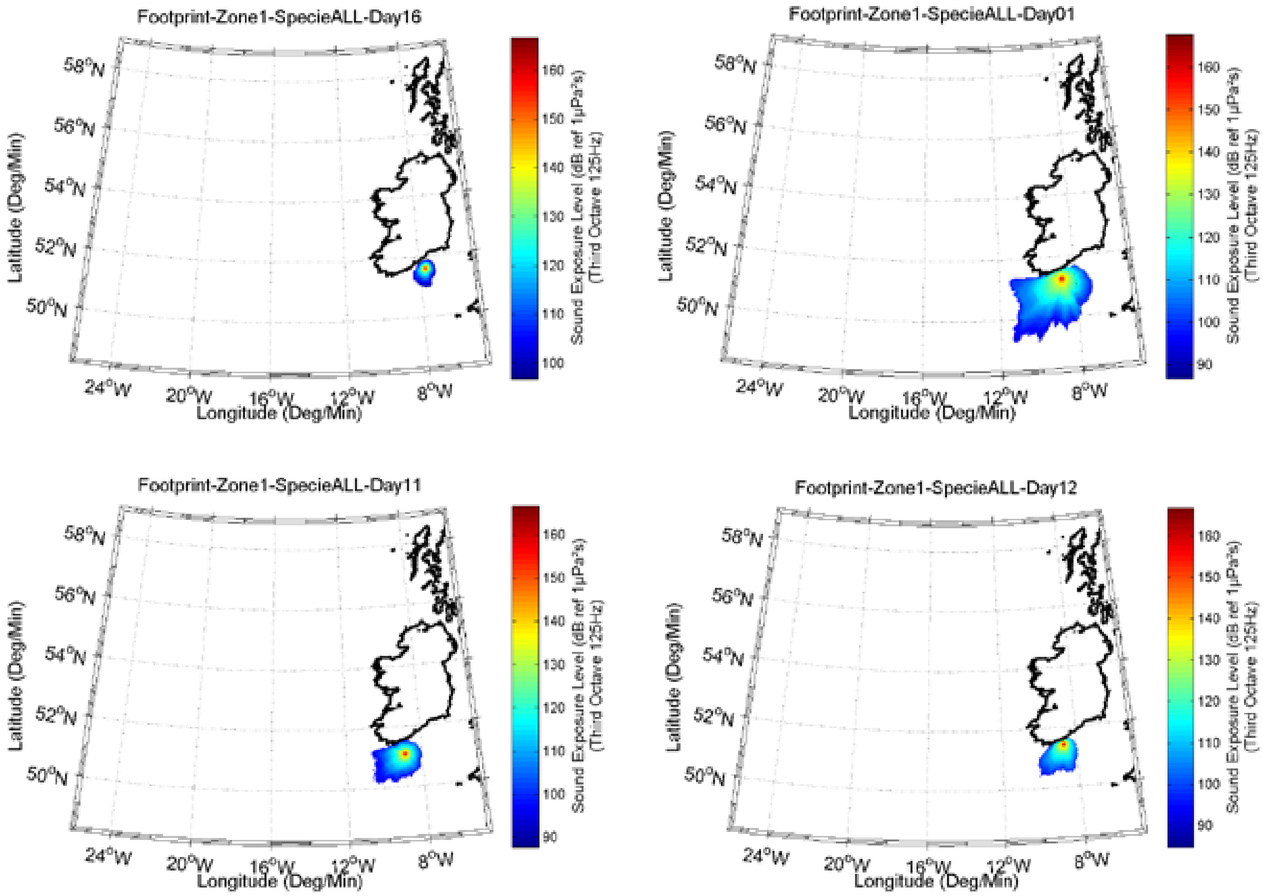


Figure 5.2. Seismic footprint for 4 cells during Survey No. 34 (2011/06/09–2000/07/02), illustrating variability on seismic footprint from a single pulse due to changes in location within survey area. Survey covered 18 cells in total.

This has major implications for any proposed monitoring programme for Irish waters. The topographic context (and its impact on pattern of sound propagation) must be taken into account during the selection of monitoring sites, whose location should not be determined on the basis of sound fields derived from simplistic power-propagation calculations (of the form α.log(r)[16]), which are often used. The relationship between footprint size and depth also suggests the need for increasing the grid size in proportion to depth (and conversely reducing the grid cell size in shallower water to improve resolution).

16 Where α is an empirical number usually chosen between 10 and 20; and r is the distance to the sound source.

5.4 Cumulative Sound Exposure Footprints of Seismic Surveys in Ireland

Building on the concepts and sound maps introduced in the previous section which dealt with individual sound pulses within a given seismic survey, we now address the extent of sound exposure footprints resulting from the cumulative energy introduced into the environment, over the duration of entire surveys. Southall et al. (2007) recommended the assessment of cumulative exposure since it is likely ‘to entail significant impact on marine animals’ (MSFD, European Commission, 2010). Figure 5.3 (a) shows the cumulative energy for all of Survey No. 6, the total cumulative energy arising from the total number of pulses with the airgun moving day by day across 15

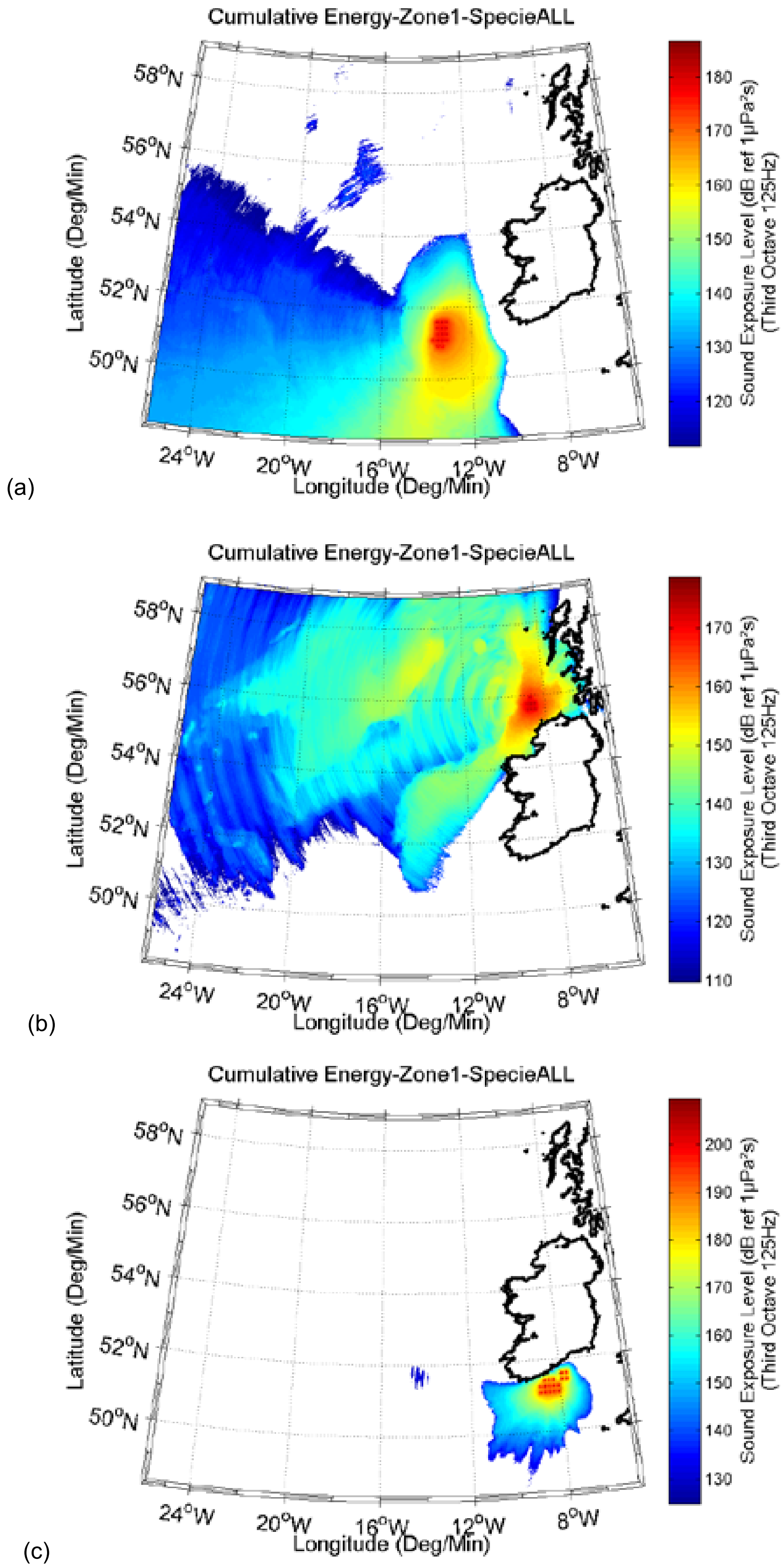


Figure 5.3. Cumulative energy of a single airgun footprint (total 82 080 pulses or 5 472 pulses/cell) for (a) Survey No. 6 which occurred in summer 2000; (b) Survey No. 3 which occurred in spring 2000 (total 25920 pulses); (c) for Survey No. 34 in spring 2011.

cells during the time period of the survey. The footprint is conspicuously asymmetrical (rather than a simple sphere), which arises from the environmental context of the survey (in terms of the spatial variability of the bathymetric terrain, and the movement of the source through that terrain). Similarly, Fig. 5.3 (b) shows the cumulative sound energy footprint for Survey No. 3. The footprint shares some characteristics with the sound map for ship traffic with a resurgence across the Rockall Bank owing to a concentration of energy in the shallower water. In the case of Survey No. 34, (Fig 5.3 (c)), the cumulative footprint is quite similar to that resulting from a single pulse. The footprint extends further towards the south-west which is likely due to the relatively low ambient noise.

6 Perceived Footprint of Seismic Survey Operations

In previous sections the focus has been on pressures. This section addresses what is received and perceived by marine mammals in Irish waters, and how these species may potentially be affected.

6.1 Species and Habitats in Ireland

Information from the MSFD Expert Consultative Group (ECG) on the 'Introduction of energy, including underwater noise' (Descriptor 11) suggested MSFD functional groups of 'baleen whales', 'toothed whales' and 'pinnipeds'. However, a strong case can be made that it is more appropriate to base functional groups on hearing sensitivity, hence the current research opted to divide marine mammal species into functional groups of 'high-', 'mid-', and 'low-' frequency cetaceans, plus 'pinnipeds' based on this distinction. The relative sensitivity of each species is based on Southall et al. (2007). Furthermore, information on the diving capabilities and depth preferences of marine mammal species was collated in order to integrate a measure of habitat preference into noise-propagation modelling and subsequent risk calculation (Table 6.1). Risk assessment is based on four depth ranges, with the assessment taking into account water column partitioning by filtering out noise that occurs below the preferred depth range of species.

Existing effort-based cetacean sighting data sets for Irish waters were compiled from the European Seabirds At Sea (ESAS), Irish Whale and Dolphin Group (IWDG), Coastal & Marine Research Centre (CMRC), and Galway-Mayo Institute of Technology (GMIT) PreCAST survey databases. Only effort-based data were used for this study, because determining the likelihood of marine mammals being in a given area at any one time requires information on the sighting effort. Data on the at-sea distribution of seals based on telemetry studies was provided by the Sea Mammal Research Unit (SMRU). ESAS and CMRC data are collected on the basis of encounters per km of survey track line, while GMIT and IWDG data are recorded as the number of individuals sighted per unit of time. Therefore, ESAS and CMRC data were converted to observations per unit time before combining with IWDG and GMIT data following the method of Reid et al. (2003). Cetacean data were pooled into functional groups based on hearing sensitivity, and gridded on one-quarter International Council for Exploration of the Seas (ICES) rectangles (0.25° latitude x 0.5° longitude). Species recorded as 'unidentified large whale' were assumed to be baleen whales and thus assigned to the 'low-frequency' functional group. Unidentified small whales were removed from the data set as they could not be confidently assigned to a functional group. No species-specific correction factors were applied to sighting effort as such an analysis is outside the scope of the current EPA noise project. Since there is a recognised effect of sea state on the detectability of marine mammals, particularly less conspicuous species such as minke whale and harbour porpoise, the data represent a conservative underestimate of marine mammal abundance.

Figure 6.1 shows the spatial distribution of sampling effort (hours of survey in each ICES quarter grid square) across the ESAS, IWDG, GMIT and CMRC data sets, and highlights the inshore bias in the distribution of sampling effort across all seasons as well as reduced effort in autumn and winter. Predictions of cetacean abundance in grid cells that have less than 5 hours of survey data should be interpreted with caution.

Table 6.1. List of marine mammals in Irish waters wth acoustical classification by sensitivity class (defined by Southall et al., 2007), and depth preferences from published sources.

Species		Classification (Southall et al., 2007)		Preferred depth range				
Comon Name	**Genus**	**Group**	**Abbreviation**	**0–100m**	**0–200m**	**0–500m**	**0–1000m**	**Reference**
Right whale	*Eubalaena*	Low-frequency cetaceans	LF		■			Watwood & Buonantony (2012)
Humpback whale	*Megaptera*	Low-frequency cetaceans	LF		■			Hamilton et al. (1997)
Blue, Minke, Sei	*Balaenoptera*	Low-frequency cetaceans	LF	■				Watwood & Buonantony (2012)
False killer whale	*Pseudorca*	Mid-frequency cetaceans	MF			■		Odell & McClune (1999)
Bottlenose whale	*Hyperodon*	Mid-frequency cetaceans	MF				■	Hooker & Baird (1999)
Bottlenose dolphin	*Tursiops*	Mid-frequency cetaceans	MF	■				Watwood & Buonantony (2012)
Striped dolphin	*Stenella*	Mid-frequency cetaceans	MF		■			Watwood & Buonantony (2012)
Killer whale	*Orcinus*	Mid-frequency cetaceans	MF		■			Watwood & Buonantony (2012)
Beaked whale	*Mesoplodon*	Mid-frequency cetaceans	MF				■	Watwood & Buonantony (2012)
Pilot whale	*Globicephala*	Mid-frequency cetaceans	MF			■		Baird et al. (2002)
Common dolphin	*Delphinus*	Mid-frequency cetaceans	MF	■				Watwood & Buonantony (2012)
Sperm whale	*Physeter*	Mid-frequency cetaceans	MF				■	Watwood et al. (2006)
Atlantic white-sided dolphin	*Lagenorhynchus*	Mid-frequency cetaceans	MF		■			Mate et al. (1994)
Risso's dolphin	*Grampus*	Mid-frequency cetaceans	MF	■				Wells et al. (2009)
Cuvier's beaked whale	*Ziphius*	Mid-frequency cetaceans	MF				■	Watwood & Buonantony (2012)
Harbour porpoise	*Phocoena*	High-frequency cetaceans	HF		■			Otani et al. (1998)
Pygmy sperm whale	*Kogia*	High-frequency cetaceans	HF			■		Watwood & Buonantony (2012)
Harbour seal	*Phoca*	Pinnipeds	P	■				Watwood & Buonantony (2012)
Grey seal	*Halichoerus*	Pinnipeds	P		■			Watwood & Buonantony (2012)

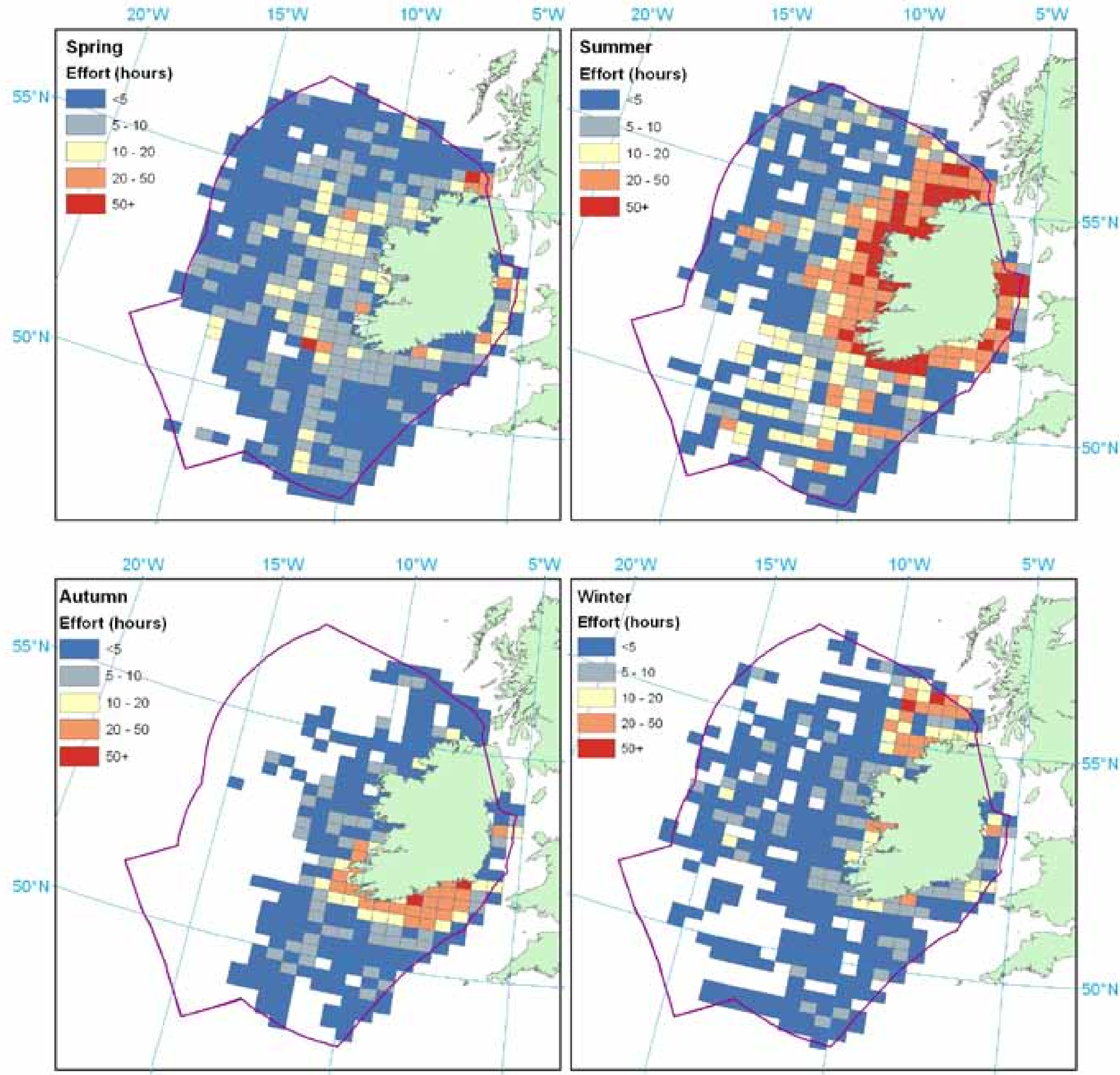


Figure 6.1. Spatial distribution of sampling effort for detection of marine mammals in Irish waters.

Figure 6.2 shows the relative abundance and distribution of cetacean species in the 'low-frequency' functional group consisting mainly of the baleen whales (Table 6.2). 'Hotspots' of abundance tend to occur offshore beyond the 200 m bathymetric contour. Similarly, Fig. 6.3 shows the relative abundance and distribution of cetacean species in the 'mid-frequency' functional group as defined by Southall et al. (2007), and consists of many species of dolphin and beaked whale (Table 6.1). 'Hotspots' of abundance tend to occur around the Rockall Bank during spring and summer. High abundances off the south coast in autumn and winter must be interpreted with caution as these areas were poorly sampled in autumn and winter months.

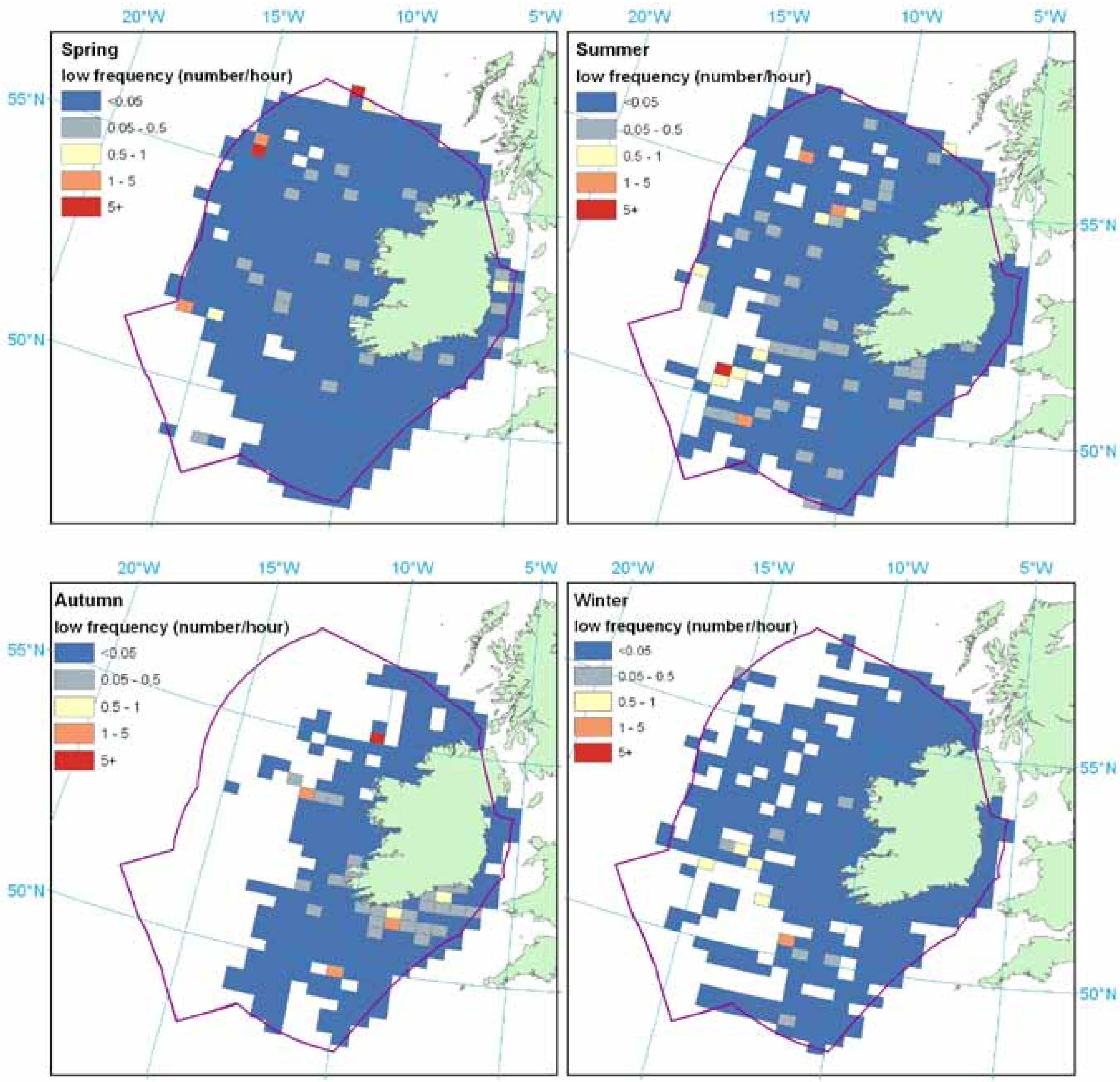


Figure 6.2. Marine mammals: spatial distribution of the low-frequency (LF) acoustical class.

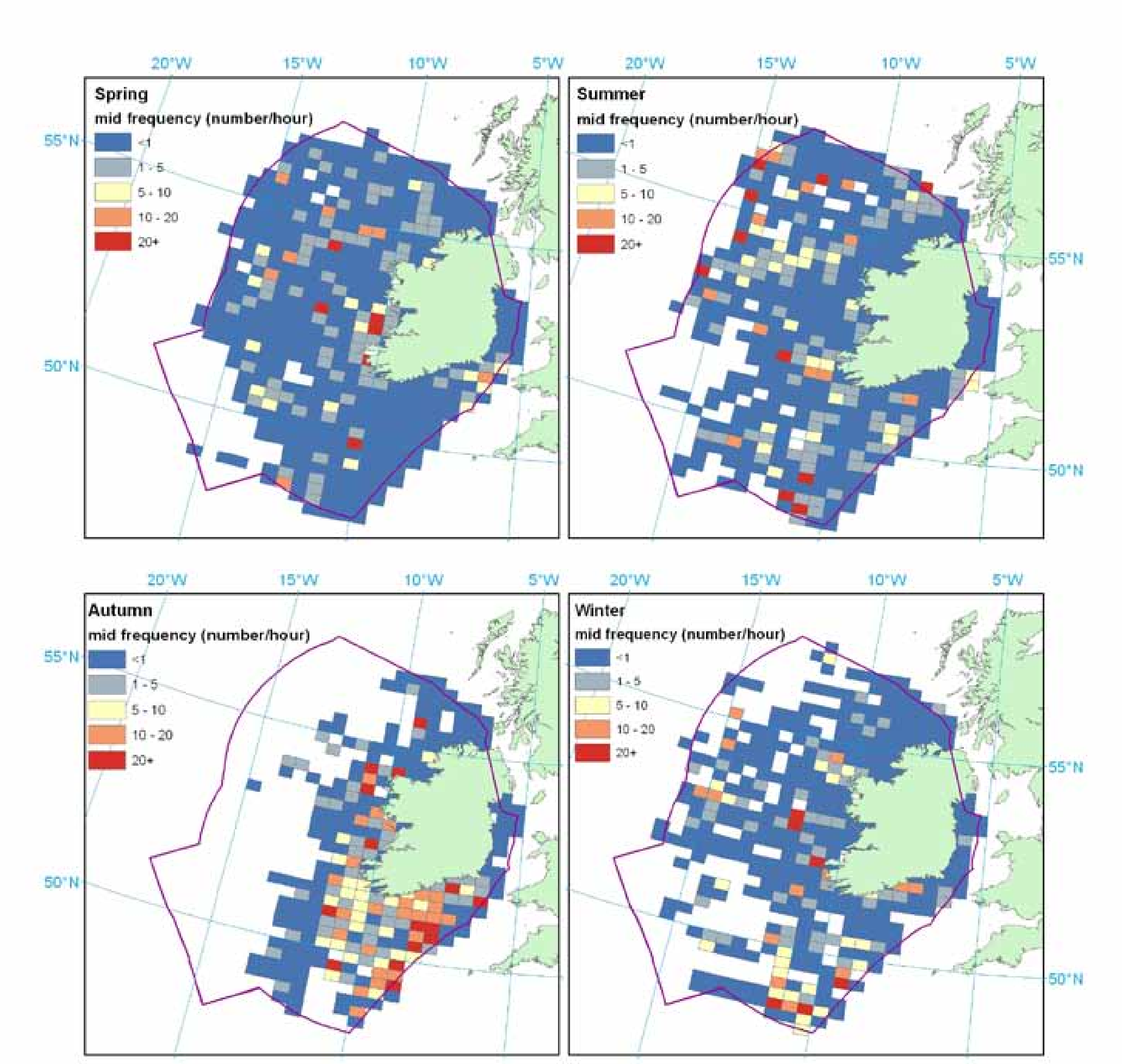


Figure 6.3. Marine mammals: spatial distribution of the mid-frequency (MF) acoustical class.

Figure 6.4 shows the relative abundance and distribution of cetacean species in the 'high frequency' functional group defined by Southall et al. (2007), consisting of harbour porpoise and pygmy sperm whale. 'Hotspots' of abundance occur close inshore, consistent with the known habitat preferences of harbour porpoise, which dominate the sightings data.

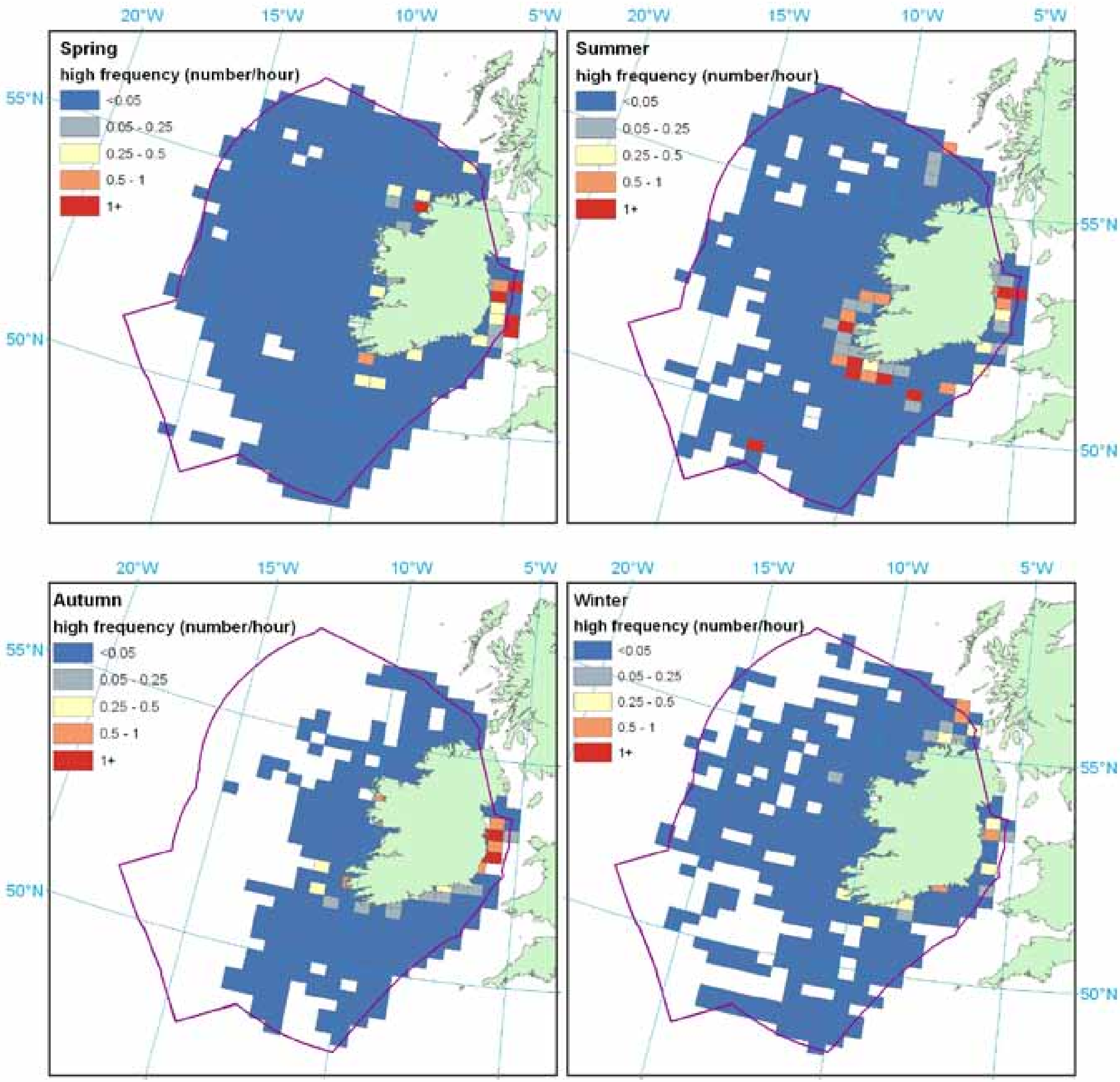


Figure 6.4. Marine mammals: spatial distribution of the high-frequency (HF) acoustical class.

Grey seal (*Halichoerus grypus*) telemetry data from 1991–2011 were combined with count data from 1988–2012 to produce at-sea estimated density, gridded as 5 km² cells by the Sea Mammal Research Unit (SMRU). Telemetry data represents variable temporal sampling effort, but Fig. 6.5 can be interpreted as the average number of seals in each 5 km² grid square at any point in time. The age and sex-structure of tagged animals may not be representative of their populations as demographic data were aggregated, and count data is not necessarily representative of breeding populations.

6.2 Methodology for Assessing Perceived Footprint

In general, impacts can potentially be observed at the level of individuals and populations. The type of effect depends on the level affected:

- At the individual level, impacts can range from behavioural change and changes in the ability to communicate, hunt or reproduce; to complete or partial physiological destruction of hearing capacity, which can lead to death in the most extreme cases;
- At the population level, impacts can range from a decrease in birth rate and an increase in infant mortality to site abandonment.

The research reported in this study only addresses the level of impact on individuals as, to date, only individual tolerance thresholds and physiological damage thresholds are known and have been quantified. This section presents the methodology for assessing and mapping the 'perceived noise footprint'.

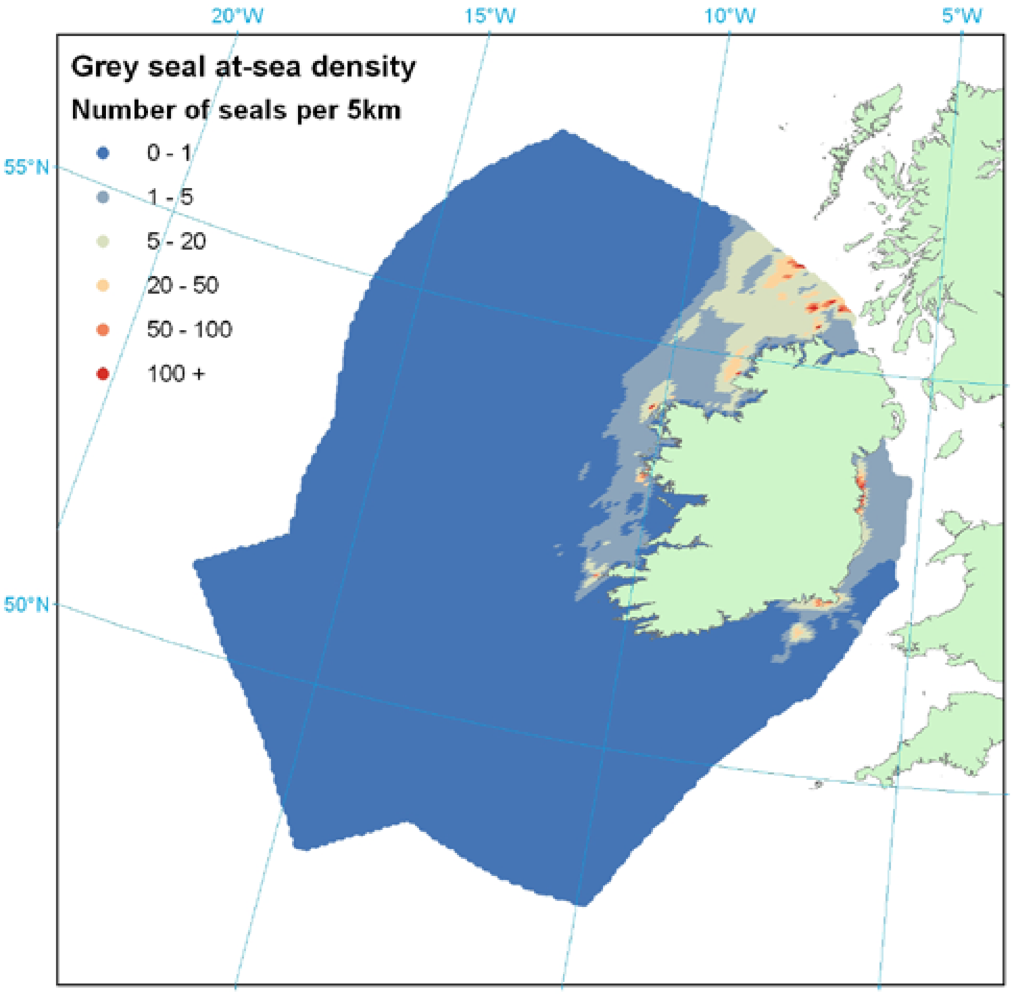


Figure 6.5. Grey seal: geographical distribution (acoustical class Pinniped [P]).

6.2.1 M-weighting

To take account of the sensitivity of each species versus frequency, sound fields established by octave are transformed into sound energy received by each class of species. This conversion procedure, proposed by Southall et al. (2007), involves selecting only the range of frequencies that humans or animals really perceive (outlined in Table 6.2). These frequency limits are used to determine, for each class of species, a band pass filter ('M-Weighting' [Southall et al., 2007]), which enables the frequency perceived by marine mammals to be taken into account. Band pass filtering for three classes of cetaceans and pinnipeds has been applied as recommended by Southall et al. (2007).

6.2.2 Biological Thresholds

Two main methods are used to analyse perceived sound energy fields: the first relative and the second absolute:

- The first method estimates tolerances in relation to the audiogram of each species, giving relative thresholds. This requires a description of the audiogram for each species present in the study area and the various tolerances involved. To date, knowledge remains limited to a few species of marine mammals and for low cumulative durations (Erbe & Farmer, 2000; Popov et al., 2011; Kastelein et al., 2012; Gervaise et al., 2012);
- The second solution compares the sound fields to the absolute values for biological thresholds defined for each class of species. These thresholds are listed in Southall et al. (2007), and are currently accepted as the only existing reference data from which it is possible to infer an impact.

The second approach has been adopted as the more conservative for the purposes of this study. To date, the literature contains reference values for biological threshold-based classes for impulsive noise integrated over a duration of 1 second, as well as other biological thresholds associated with the accumulation of sound energy over a continuous 24-hour period (Southall et al., 2007; Lucke et al., 2009). These thresholds are listed in Table 6.2. While recent studies have concerned the evolution of thresholds relative to the duration of exposure (Kastelein et al., 2012; Popov et al., 2011), these experiments were conducted for limited periods of 30 and 240 minutes respectively, which are very different to the cumulative durations considered in the current study.

6.3 Risk Assessment linked to Seismic Activities

This section quantifies the risk to marine mammals posed by anthropogenic noise fields based on the thresholds previously described. From the various values for PTS (risk of permanent hearing threshold shift) and TTS (risk of temporary hearing threshold shift) cited in the literature (see Table 6.2), five levels of risk, each linked to a threshold, are defined (Fig. 6.6):

1. Red is when the footprint is above the PTS threshold;
2. Orange is when risk is above TTS but below PTS;
3. Yellow is above thresholds for BDT (risk of behaviour disturbance) but below TTS;
4. Green is still within the noise footprint (animal can detect it) but with a low risk of disturbance;
5. White represents areas that are outside the noise footprint (the animal is unlikely to or marginally perceives the seismic activity).

Table 6.2. Acoustic thresholds for behaviour disturbance threshold (BDT), temporary threshold shift (TTS), and permanent threshold shift (PTS) derived from the literature.

Classification by Southall & all 2007	Specie in the study area	Approximate frequency range of sensitivity (M-weighting Southall et al. 2007)	Sound Exposure Level (dB ref. 1µPa2s)					
			Behavior Disturbance Threshold (BDT)		Temporary Threshold Shift (TTS)		Permanent Threshold Shift (PTS)	
			Any type of sound	Impulsive sounds	Any type of sound	Impulsive sounds	Any type of sound	Impulsive sounds
			1 sec	T[17]<24h[18]	1 sec	T[(17)]<24h[(18)]	1 sec	T[(18)]<24h[(18)]
High Frequency Cetacean	*Phocoena* *Kogia*	0,200-180kHz	**145**([19])	145+10log10(T[17/19])	**164**([19])	164+10log10(T[17/19])	**198**([20])	198+10log10(T[17/19])
Mid Frequency Cetacean	*Pseudorca* *Hyperoodon* *Tursiops* *Stenella* *Orcinus* *Mesoplodon* *Globicephala* *Delphinus* *Physeter* *Lagenorhynchus* *Grampus* *Ziphius*	0,150-160kHz	Not defined	Not defined	**183**([20])	183+10log10(T[17/19])	**198**([20])	198+10log10(T[17/19])
Low Frequency Cetacean	*Eubalaena* *Megaptera* *Balaenoptera*	0,007-22kHz	Not defined	Not defined	**183**([20])	183+10log10(T[17/19])	**198**([20])	198+10log10(T[17/19])
Pinnipeds (in water)	*Phoca* *Halichoerus*	0,075-75kHz	Not defined	Not defined	**171**([20])	171+10log10(T[17/19])	**186**([20])	186+10log10(T[17/19])

17 T is the exposure duration expressed in second.

18 Defined by Lurton (2007), « Analyse des risques pour les mammifères marins liés à l'emploi des méthodes acoustiques en océanographie » (IFREMER)°, derived from Ward (1968). This approach shows some agreement with Southall et al. (2007) for non pulse signals for 24h exposure.

19 Temporary shift in masked hearing thresholds in a harbor porpoise (Lucke, 2009).

20 Southall et al. (2007)

Since the threshold for behaviour changes are not yet established for mid- and high-frequency species, and since it is reasonable to assume that animals are likely to change behaviour before TTS, a gradient of colour proportional to the perceived noise level from green to yellow is used to indicate that the disturbance may occur at a distance from the orange area (Fig. 6.6).

In order to take into account the depth range of each species in respect to the three-dimensional nature of the sound field we have adopted a simple convention; for each species the map will show, for example, red if 50% of the depth range for that species is above the PTS threshold limits, which approximately equates to a 50% loss of habitat.

Since all the sound fields have been based on a frequency band of one-third octave of 125 Hz, it was necessary to make an adjustment to take into account the full auditory range of the animals. To account for this the noise levels have been adjusted upwards by a factor of 11 dB, which captures the energy that might be in the other frequency bands (i.e. between 63 Hz and 63 kHz).

6.3.1 Single-shot Risks

Figure 6.7 shows examples of risk maps for two classes of marine mammals associated with a single seismic pulse, Survey No. 8, first cell (averaged over 1 second). The high-frequency class (Fig 6.7 (a)) shows a distinct boundary between the area in which the sound is detectable and the yellow zone (BDT). In other words, for this single shot, the risk area appears fairly small and concentrated in the vicinity of the source. The fuzzy transition between these two zones for low-frequency species (Fig 6.7 (b)) reflects that fact that definitive thresholds are not established for these species. In general, the single-shot scenario appears to represent fairly minimal risk. However, the cumulative risk scenario differs significantly.

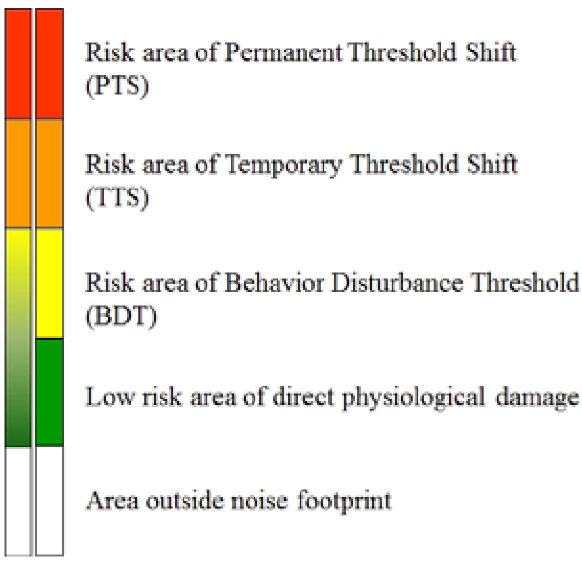


Figure 6.6. Colour scale of risk and identification.

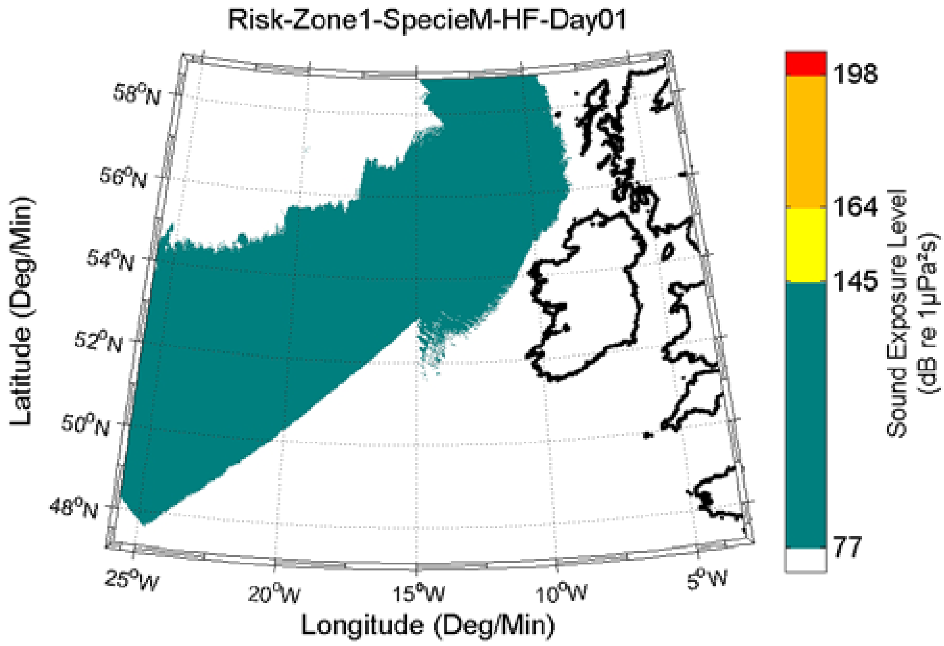


Figure 6.7 (a). Risk maps between 0 and 100 m depth, for a single shot of 3660 cubic inches in August 2003, for high-frequency marine mammals (primarily harbour porpoise in Irish waters).

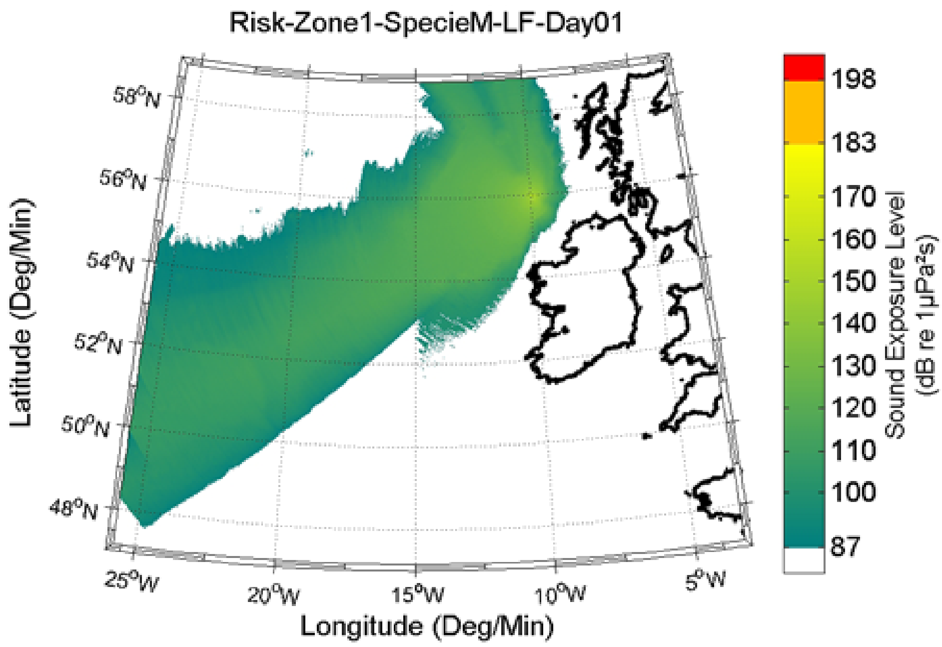


Figure 6.7 (b). Risk maps between 0 and 100 m depth, for a single shot of 3660 cubic inches in August 2003, for low-frequency cetacean species.

6.3.2 *Cumulative Risks*

Figure 6.8 presents the situation in a single grid cell in terms of cumulative risk for high frequency species associated with survey No. 8. It shows the increasing distance over which impacts on marine mammals will occur as acoustic energy accumulates from the succession of pulses over a period of 1 day (assuming the repetition rate is 20 seconds with no interruption of seismic activity during the day). This effectively provides a measure of the magnitude of cumulative risk as a function of time with the grey areas showing the variability of the threshold distance. This variability derives from the directionality of sound propagation (e.g. the bathymetric profile, the sediment properties and oceanographic context). Plots are based on the assumption that the animals are stationary and do not move away from or towards the sound source. While there is a lack of robust data on the behavioural responses of marine mammals to sound, this is highly unlikely in reality, as the range for changes in behaviour increases rapidly at the beginning of survey and then more slowly after the first 1000 seismic airgun ‘pulses’. During the first 3 hours (540 seismic pulses) an animal might travel a few kilometres away from the noise source, which will reduce exposure to sound. However, if it moves towards the sound source, exposure will increase with time.

Figure 6.9 shows the cumulative risk map scenario for the full duration of Survey No. 8 for the two classes of cetaceans (no movement assumed). The extent of the higher-risk area is clearly very much broader than the previous plots and may give cause for concern when viewed in the context of the MSFD clauses on impulsive sounds:

> 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 Sound Exposure Level (in dB re 1μPa^2·s) or as peak sound pressure level (in dB re 1μPa$_{peak}$) at one metre, measured over the frequency band 10 Hz to 10 kHz (Indicator 11.1.1).
>
> (European Commission, 2010)

The size of area that may entail significant impact is very much more extensive and irregular than may be inferred from maps presented in the typical ‘pulse-

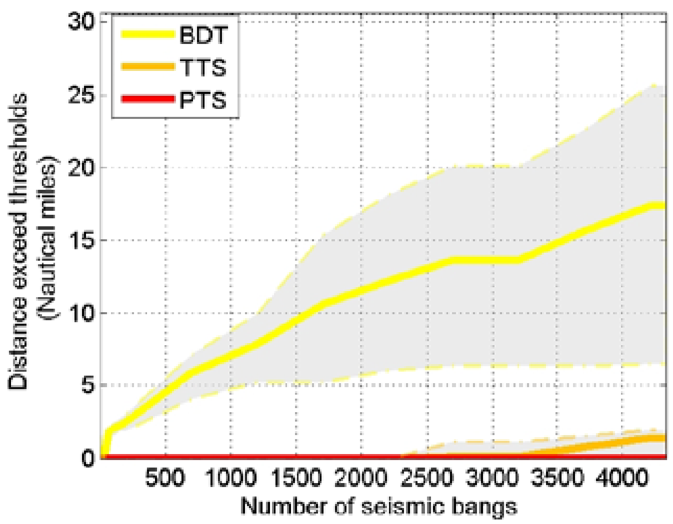


Figure 6.8. Cumulative increase in risk of behaviour disturbance threshold (BDT), temporary threshold shift (TTS), and permanent threshold shift (PTS) from successive seismic pulses between 0 and 100 m depth for high-frequency species. Model outputs are constrained by the assumption that animals remain stationary and do not move towards, or away from the sound source. The grey area represents the spatial variability of the risk around the sound source.

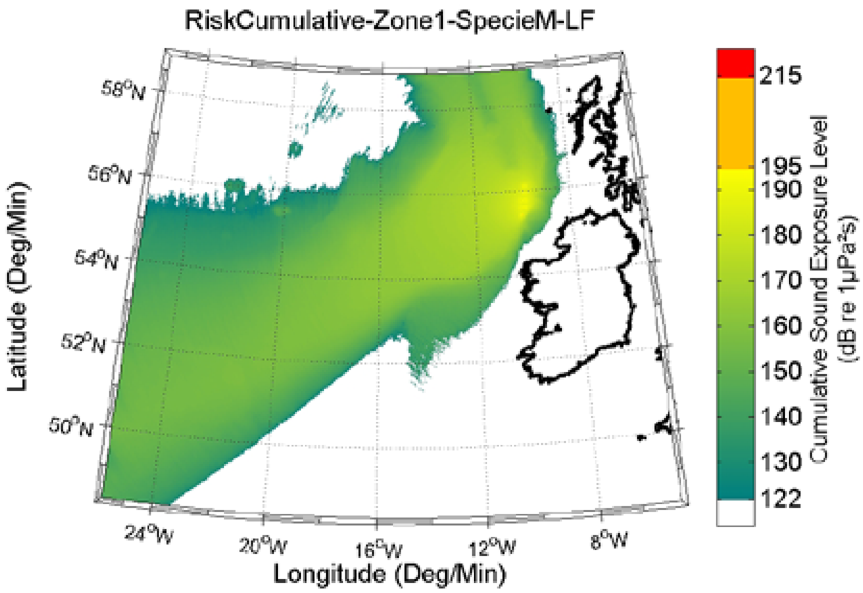


Figure 6.9 (a). Cumulative risk at the end of the full duration of Survey No. 8 (30 240 seismic airgun pulses) between 0 and 100 m depth, for low-frequency species. Assumption is made that the species are not significantly escaping the area during the survey.

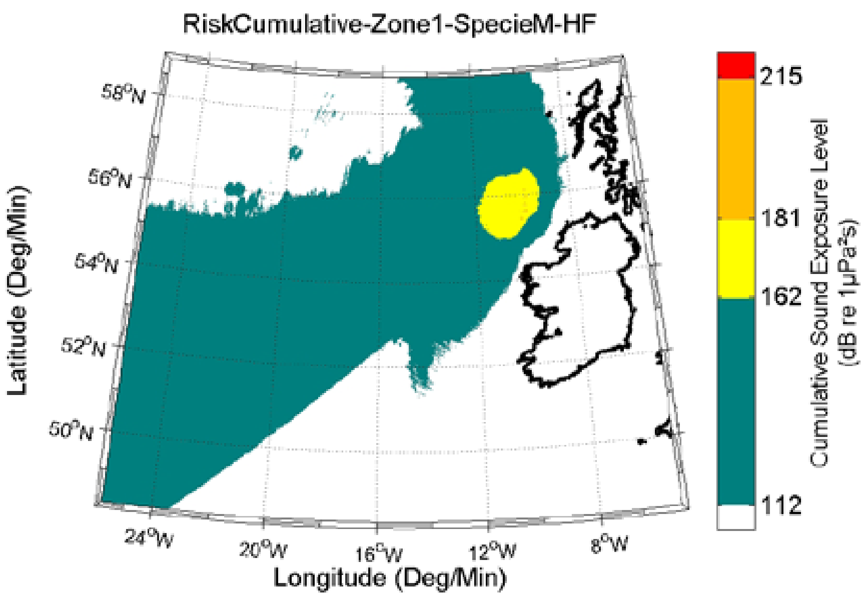


Figure 6.9 (b). Cumulative risk at the end of the full duration of Survey No. 8 (30 240 seismic airgun pulses) between 0 and 100 m depth, for high-frequency species. Assumption is made that the species are not significantly escaping the area during the survey.

block-days' reporting format, and may result in areas of impact that completely encompass the preferred habitat or range of some marine mammal species. This approach also points strongly to the potential to use this type of predictive risk mapping as a guideline reference for predicting the potential impact of future surveys.

6.4 Overlap of Noise Risk and Marine Mammal Distribution

Survey No 8 was conducted in August 2003, overlapping with the summer/autumn distribution of marine mammals as outlined in Section 6.1. Overlaying the ‘cumulative noise risk’ with the distribution of marine mammals shows potential overlap of adverse noise conditions with areas of marine mammal ‘hotspots’ (Fig. 6.10). The area of detectability over environmental noise and the cumulative risk of behavioral changes do not overlap with high densities of high-frequency marine mammals, which tend to have a more inshore distribution. It should be noted that the potential overlap is only valid for Survey No. 8, and is not representative of cumulative impacts from surveys of differing durations or locations. (See Section 5.3 for information relating to the variability of impulsive noise footprints in Ireland.)

The combination of cumulative noise risk and low-frequency marine mammal distribution (Fig. 6.11) shows an overlap between areas of potential temporary hearing behavioral changes and areas of intermediate and high abundance of low-frequency marine mammals, particularly in summer months. There is also significant overlap between the area of detectability and

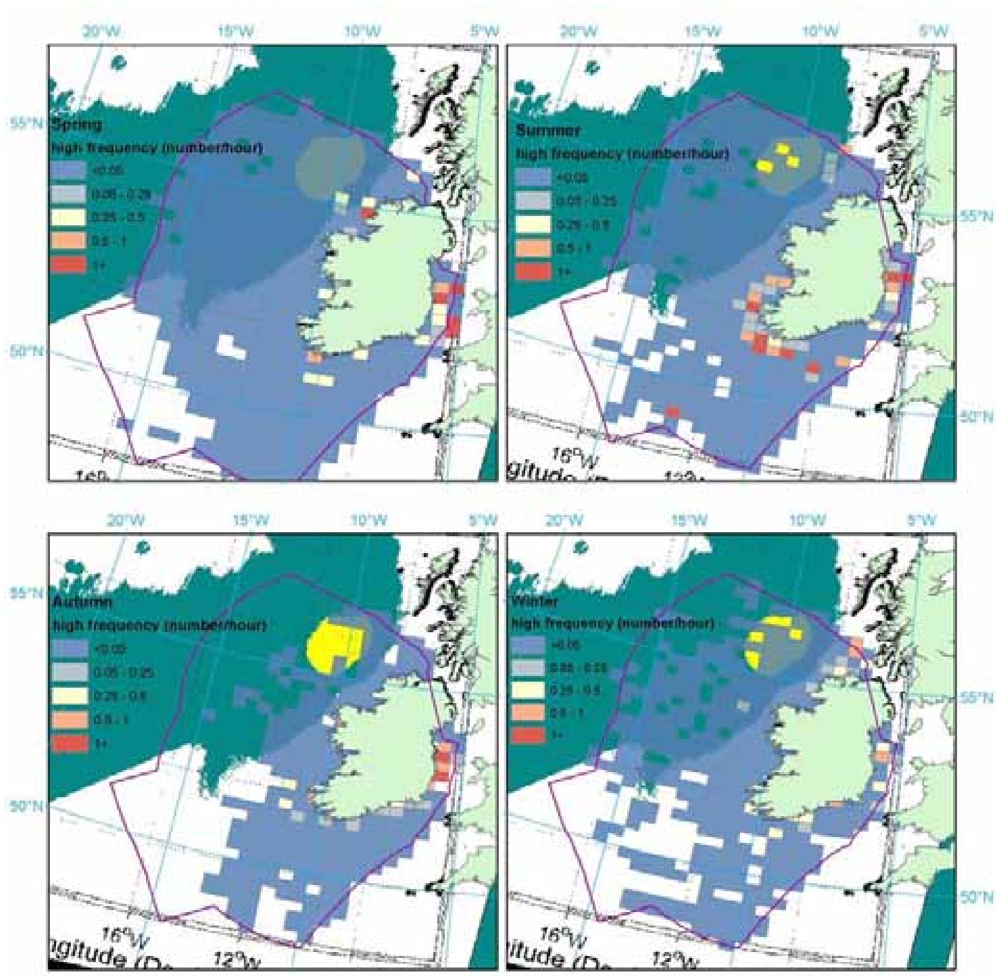


Figure 6.10. Overlap of cumulative noise risk with high-frequency marine mammal distribution in spring and summer.

the distribution of low-frequency marine mammals. This suggests the potential for seasonal mitigation strategies, wherein seismic surveys (whilst acknowledging operational constraints) of this kind may be encouraged to avail of less sensitive months, for example during spring. The extensive area of detectability of noise and potential behavioural change, extending far offshore largely due to bathymetry, may be a cause for concern, particularly if noise interferes with or masks biological cues used for communication or foraging. Again, the potential overlap is only valid for Survey No. 8, and is not representative of cumulative impacts from surveys of differing durations or locations.

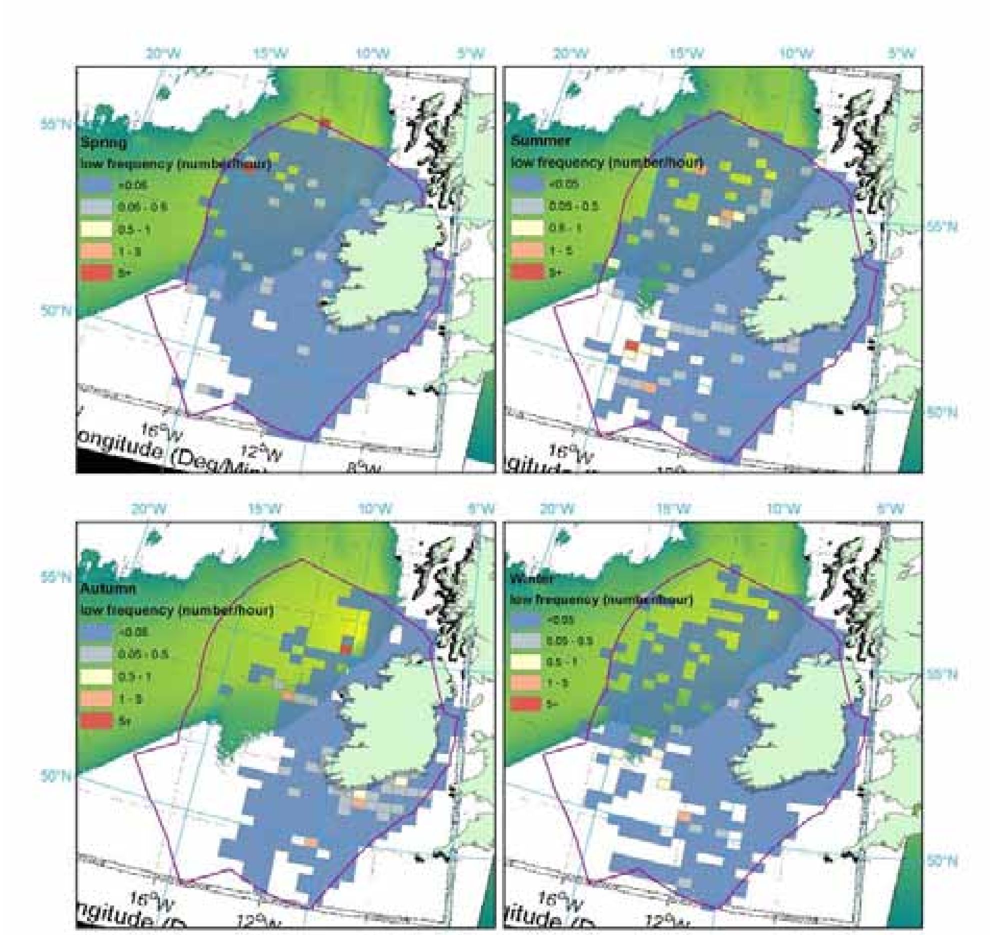


Figure 6.11. Overlap of cumulative noise risk with low-frequency marine mammal distribution in spring and summer.

7 Conclusions

7.1 General Observations

The MSFD adopted in June 2008 is intended to protect the marine environment across Europe more effectively. It aims to achieve Good Environmental Status of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend.

This is clearly important in the context of marine planning (MSP), Strategic Environmental Assessment (SEA), and other marine environmental policies. MSFD requirements also have a strong bearing in relation to the regulatory framework that is in place to manage the cumulative and in-combination impacts of various underwater sound sources, including for example: prospecting for hydrocarbons; construction of coastal infrastructure, and during the emplacement of offshore renewable energy devices.

The project was one of the first in Ireland to undertake a systematic quantification and mapping of the extent and intensity of underwater anthropogenic noise. In this regard the products of the work represent a revealing milestone in our perception and understanding of this important but often overlooked dimension of our impact on the Irish marine environment. The work also represents a definitive contribution in respect of our national obligation towards the achievement of good environmental status under Descriptor 11 of the MSFD.

The considerable size and extent of the Irish maritime area over which the State exercises jurisdiction and exclusive sovereign rights, suggests that high costs will be involved in effectively monitoring and reporting the status of anthropogenic noise. This is because attaining full acoustic coverage of the entire EEZ would require the deployment of a large number of vulnerable underwater sound-recording instruments. In this context the outputs of this project are immediately and specifically relevant. By adopting and effectively localising a statistically robust and proven modelling approach we have demonstrated the viability of an alternative solution. Conservatively this combined modelling/observations approach would initially entail the deployment of a number (6-10) strategically located recorders, the aim being to reduce the number of deployments in time as confidence in the modelled outputs increases.

In considering the cost implications of a sound recording network, we also recognise that there may be some potential to partly offset future monitoring costs through mechanisms connected to the evolving licensing protocols around the management of offshore activities.

7.2 Specific Conclusions

The project steering and review committees were unified in confirming that the project has fully met the specific objectives as set out in Section 1.2 above. From the programme of work undertaken and results obtained it is clear that the seasonal noise maps provide an intuitive and broadly accessible means to present, communicate and highlight the often complex characteristics of ambient sound fields experienced in Irish waters as they vary across seasons and between regions.

In this regard, the results have also highlighted the importance of obtaining and integrating high-quality data of sufficient resolution not only to characterise the sources (and source levels) of natural and anthropogenic sound, but also to take account of the key environmental parameters (and their variability) that influence sound propagation (bathymetric terrain, water temperature, seabed and sea-surface roughness, etc.).

In practice, collating and integrating such data for Irish waters was far from straight forward, again highlighting the need for considerable for improvement in the ready availability of key environmental data sets (and associated metadata) at appropriate resolution in suitable and standards-compliant formats. Moreover, the effort has also highlighted areas where there is potential to enhance the reporting, registration and ready availability of key parameters describing anthropogenic noise inputs, such as those associated with shipping (vessel signatures) and seismic exploration (more complete descriptions of equipment and operational parameters), which would enable more accurate quantification of source levels of inputs to the environment.

The following specific conclusions were identified, and these are presented together with recommendations and an articulation of future research requirements.

7.2.1 *Continuous Sound*

- Ship traffic noise can spread over very large areas, well beyond the standard navigation routes. *The Atlas of Continuous Noise* suggests that Irish waters are relatively quiet when compared with areas that are close to shipping routes, for example the channel separation zone. (The analogy here is of a house situated at remove from a motorway experiencing the background hum of traffic in the distance);
- Long-term (e.g. minimum eight days for Cork but up to yearlong to capture seasonal trends) but relatively short duty cycle (2% for Cork in summer) acoustic monitoring is sufficient to capture continuous noise sources. Such configuration is likely to have low power consumption; (and so reduced maintenance and at-sea service), making it compatible with available restricted bandwidth real-time offshore data-transfer mechanisms
- Concurrent high-resolution local time series environmental data sets are essential for calibrating the acoustic data and identifying potential trends;
- Use of percentiles as a metric for reporting is essential because of the stochastic nature of noise, and to obtain both a statistical descriptor and information suitable to assess the significance of the noise impacts on target species;
- To capture the variability of shipping noise, the duration and precise positioning of acoustic monitoring will need to vary with shipping density, frequency and transit routes. We therefore recommend an approach to this that uses AIS data as proxy to initially inform the logistics of the national monitoring strategy.

7.2.2 *Seismic Activity*

- The noise ‘footprints’ from seismic activity are very dependent on the location (depth/topography) and season of the survey, and cannot be predicted without using modelling-simulation techniques that can account for these key variables;
- The potential risks to marine mammals posed by the sound fields associated with single shots are localised to the source itself. However, cumulative sound fields arising from multiple shots either within a survey or from multiple concurrent surveys generate very large areas of potential risk, again with variability depending on season and location;
- The magnitude of the areas affected by cumulative risk is much larger, and much more variable than would be predicted by the current ‘pulse-block-days’ approach and associated grid-reporting system. While the ‘pulse-block-days’ approach is simple to implement, its appropriateness is questionable, since reporting should also address the potential for damage to vulnerable species;
- Dedicated prediction of noise footprint and biological risks should be included in any environmental impact assessment (EIA) for seismic survey activities.

7.2.3 *Potential Monitoring Network*

In keeping with the reference above and in line with draft recommendations contained in the guidelines being developed by the TSG Noise Group (Dekeling et al., 2013) the concept of a systematic and complete underwater monitoring network that would be capable of providing fully comprehensive cover for all Irish waters for the purposes of reporting on MSFD Descriptor 11 would appear to unfeasible on grounds of cost. Hence, we recommend an approach which combines (a) an appropriate modelling framework (and associated sound maps), with (b) strategic device deployments as a means of acquiring field data from which appropriate statistical trends can be directly extracted, and which can be used as a source of calibration and verification data for the models. The type and location of actual device deployments will be a compromise based on the balancing of key factors, including:

- Unit and operation and maintenance (O&M) costs;
- Availability of existing infrastructure for mounting: e.g. buoys, *in situ* power/data cables, hard infrastructure (quays/piles/platforms);
- Availability of logistic support (potential synergies with existing operations): operational deployment, ongoing maintenance and data-transmission/analysis;
- Final placement relative to localised site conditions, currents, proximity to shipping lanes, likelihood of loss due to trawling or other submarine activity, anchoring substrate, potential to avoid or mitigate self-noise induced by the monitoring device itself, its housing and/or the object or surface it is mounted on;

- The prevailing ambient (continuous) and impulsive sound fields based on existing knowledge, modelled data and or proxy information, for example from AIS maps.

In view of these factors and in the light of the project outputs (noise-risk maps, experimental deployment findings, cetacean distribution maps). Table 7.1 presents an overview that can be used as an initial basis for the design of a monitoring programme.

Consideration should also be given to utilising the existing meteorological/oceanographic databuoy network operated by the Marine Institute (http://www.marine.ie/home/publicationsdata/data/buoys/). These buoys are located at strategically relevant locations around the coast: however, there are significant logistical constraints which would have to be taken into consideration including:

- Power and payload constraints;
- Logistical and O&M limitations (mountings, self-noise from moorings, data transfer capacity).

7.3 Recommendations for Implementation and Uptake of Research Findings

7.3.1 Summary Recommendations

There is a general need to increase the awareness in the offshore industry of the pivotal role of the environment in noise propagation and the noise impact of activities on marine mammal populations in Irish waters. This project emphasises the need for changes in the reporting requirements of seismic activities in Irish and European waters. Mathematical modelling systems should be employed as routine tools for monitoring, evaluation and management of noise risks associated with all types of offshore activities, and further development of geographical information systems for application in EIA contexts should be supported. A summary of issues, recommendations and timeframes is given in Table 7.2.

Table 7.1. Overview of potential underwater noise monitoring network in Irish waters.

Regional coverage	Location	Comment/rationale	Placement/mounting type	Existing?
South & and south-east inner shelf	Cork Harbour Mouth	Major shipping port, partially resident cetacean population	Newly deployed smartbuoy-potential for shore-side data delivery	Imminent 2014
South and south-east mid-shelf	Kinsale Head Gas Installations	Strategic location in mid-shelf potentially in range of Channel shipping zone	On or in association with existing hydrocarbon fixed infrastructure	No
Part of outer Shannon Estuary	River Shannon	Minor port and resident cetacean population. Highly localised coverage in shallow water	Fixed and connected to Lido infrastructure	Yes
Inner Galway Bay	Oranmore-Smartbay monitoring	Currently monitoring conducted for purposes of optimising characterisation of signatures of ORE devices. Highly localised coverage in shallow water	Seabed and buoys	Yes 2013
Mid Galway Bay	New Smartbay cabled observation network	Potential to obtain wider coverage of Galway Bay together with direct delivery of data ashore and constant power supply	Seabed and buoys	Imminent 2014
Most of Irish EEZ to the west of landmass	Rockall Bank	Highly strategic location at point resurgence of sound from a very wide deep-water area. Suitable for monitoring impacts of west-coast seismic surveys	TBC: buoy, benthic lander as part of an integrated oceanographic station, autonomous seabed device	No
Dublin Bay	Potentially buoy M2, or in association with various navigation marks or fixed infrastructure	Major port with intensive shipping activity	TBC	No

Table 7.2. Summary of recommendations for the implementation and uptake of research findings.

Issue	Recommendation	Target[21]	Time frame
MI smart buoy network and other existing infrastructure as sound-monitoring platforms	Investigate and assess suitability and potential for use. Refer to Sect 7.2.3 above for further details	MI, DECLG, EPA	Short term
Relatively low base nationally in terms of knowledge, capacity and integrated policy (government departments and state agencies) with respect to underwater sound (MSFD) and marine spatial planning (MSP)	Expand existing research initiatives and consolidate access to recognised technical consultative expertise, platforms, tools and information on a sustainable cross-departmental and inter-agency cooperative basis	EPA, DECLG, DCENR, MI, An Bord Pleanála,. SEAI	Short, medium and long term
Poor awareness of the link between the environment and noise propagation	Development of GIS repository of 'snapshots/ cumulative impacts' for referral and awareness raising by industry	EPA, DECLG, PAD, OOG and Industry,	Short term
Perceived shortcomings in 'pulse-block-days' reporting	Recognition of inadequacy of 'pulse-block -day' as an effective indicator of impulsive noise impact programme of action to have alternative noise reporting framework addressed at TSG Noise	Industry, DCENR, TSG	Short/medium term
Lack of suitable marine mammal distribution data	Collation of all relevant data and submission to National Biodiversity Monitoring programme to assess potential risks of seismic/construction activities Filling of priority data gaps in marine mammal distribution data sets	Researchers/ NGOs, OOG, PIP, NPWS	Medium/long term
Gaps in environmental impact assessments	Support development of Web-GIS for EIA giving indication of potential footprint from seismic activities at various locations in EEZ. This could be further developed into a decision-support system possibly using web-based technology	EPA, DECLG, NPWS, OOG	Short term
National knowledge and capacity gaps in relation to science on sources and impacts of underwater noise and capacity for MSFD reporting in terms of D11	Continued strategic investment in capacity-building, and coordinated cooperative approach across existing academic and industrial research community to address key questions, e.g. (establishing thresholds for Good Environmental Status) and review within timeframe of MSFD reporting	EPA, MI, HEA, TSG Noise, Academia, Industry (Offshore renewable energy, shipping and hydrocarbon)	Short/medium term
Lack of detail in seismic activity reporting	Additional parameters to be recorded in the register and databases arising from seismic surveys including seismic survey repetition rates, duration of operational hours on a daily basis	DCENR-PAD, Hydrocarbons Industry	Short term

DCENR – Department of Communication, Energy and Natural Resources; DECLG Department of the Community, Environment and Local Government; EPA – Environmental Protection Agency; HEA – Higher Education Authority; MI – Irish Marine Institute; NGOs – Non-Governmental Organisations; NPWS – National Parks & Wildlife Service; OOG – Offshore Oil & Gas Industry; PAD – Petroleum Affairs Division; PIP – Petroleum Infrastructure Programme; SEAI – Sustainable Energy Authority of Ireland; TSG – Technical Steering Group on Noise.

21 In this column we have interpreted 'target' to mean those organisations for which there is relevance beyond the strict sense of being the formal 'competent authority'. E.g. for the issue 'lack of suitable marine mammal distribution data', the PIP (Petroleum Infrastructure Programme) is listed because they often fund research in this area and would be in a position to facilitate the collection and appropriate dissemination of strategically valuable data sets.

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Acronyms and Annotations

AIS	Automatic Identification System
CMRC	Coastal & Marine Research Centre, University College Cork
DCENR	Department of Communication, Energy and Natural Resources
DECLG	Department of Environment, Community and Local Government
ECG	Expert Consultative Group
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
ESAS	European Seabirds At Sea
GEBCO	GEneral bathymetric Chart of the Oceans
GMIT	Galway-Mayo Institute of Technology
HEA	Higher Education Authority
HF	High frequency
ICES	International Council for Exploration of the Seas
IOC	Intergovernmental Oceanographic Commission
IHO	International Hydrographic Organization
IWDG	Irish Whale and Dolphin Group
LF	Low frequency
MI	Marine Institute
MF	Mid frequency
MSFD	Marine Strategy Framework Directive
NPWS	National Parks & Wildlife Service
NRC	National Research Council
OOG	Offshore Oil and Gas Industry
PAD	Petroleum Affairs Division
PDF	Probability density function
PIP	Petroleum Infrastructure Programme
RMS	Root mean square

SEL Sound exposure level

SMRU Sea Mammal Research Unit

TG Task group

TSG EU Technical Sub Group on the Effects of Underwater Noise on the Marine Environment

TTS Threshold shift

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht 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. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe 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 peitreail;
- 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 comhordú 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 TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil 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 caighdéan aeir 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 Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta 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 imní 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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