

STRIVE

Report Series No.96

Assessment and Monitoring of Ocean Noise in Irish Waters

STRIVE

Environmental Protection
Agency Programme

2007-2013

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.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Community and Local Government.

OUR RESPONSIBILITIES

LICENSING

We license the following to ensure that their emissions do not endanger human health or harm the environment:

- waste facilities (e.g., landfills, incinerators, waste transfer stations);
- large scale industrial activities (e.g., pharmaceutical manufacturing, cement manufacturing, power plants);
- intensive agriculture;
- the contained use and controlled release of Genetically Modified Organisms (GMOs);
- large petrol storage facilities;
- waste water discharges.

NATIONAL ENVIRONMENTAL ENFORCEMENT

- Conducting over 2,000 audits and inspections of EPA licensed facilities every year.
- Overseeing local authorities' environmental protection responsibilities in the areas of - air, noise, waste, waste-water and water quality.
- Working with local authorities and the Gardaí to stamp out illegal waste activity by co-ordinating a national enforcement network, targeting offenders, conducting investigations and overseeing remediation.
- Prosecuting those who flout environmental law and damage the environment as a result of their actions.

MONITORING, ANALYSING AND REPORTING ON THE ENVIRONMENT

- Monitoring air quality and the quality of rivers, lakes, tidal waters and ground waters; measuring water levels and river flows.
- Independent reporting to inform decision making by national and local government.

REGULATING IRELAND'S GREENHOUSE GAS EMISSIONS

- Quantifying Ireland's emissions of greenhouse gases in the context of our Kyoto commitments.
- Implementing the Emissions Trading Directive, involving over 100 companies who are major generators of carbon dioxide in Ireland.

ENVIRONMENTAL RESEARCH AND DEVELOPMENT

- Co-ordinating research on environmental issues (including air and water quality, climate change, biodiversity, environmental technologies).

STRATEGIC ENVIRONMENTAL ASSESSMENT

- Assessing the impact of plans and programmes on the Irish environment (such as waste management and development plans).

ENVIRONMENTAL PLANNING, EDUCATION AND GUIDANCE

- Providing guidance to the public and to industry on various environmental topics (including licence applications, waste prevention and environmental regulations).
- Generating greater environmental awareness (through environmental television programmes and primary and secondary schools' resource packs).

PROACTIVE WASTE MANAGEMENT

- Promoting waste prevention and minimisation projects through the co-ordination of the National Waste Prevention Programme, including input into the implementation of Producer Responsibility Initiatives.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

MANAGEMENT AND STRUCTURE OF THE EPA

The organisation is managed by a full time Board, consisting of a Director General and four Directors.

The work of the EPA is carried out across four offices:

- Office of Climate, Licensing and Resource Use
- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

EPA STRIVE Programme 2007–2013

Assessment and Monitoring of Ocean Noise in Irish Waters

**Assessment of Indicator 11.1.1 – Register of Impulsive Noise
from Seismic Surveys**

(2011-W-MS-6)

STRIVE Report

Prepared for the Environmental Protection Agency

by

Galway–Mayo Institute of Technology

Authors:

Suzanne Beck, Joanne O’Brien, Ian O’Connor and Simon Berrow

ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699

Email: info@epa.ie Website: www.epa.ie

DISCLAIMER

Although every effort has been made to ensure the accuracy of the material contained in this publication, complete accuracy cannot be guaranteed. Neither the Environmental Protection Agency nor the author(s) accept any responsibility whatsoever for loss or damage occasioned or claimed to have been occasioned, in part or in full, as a consequence of any person acting, or refraining from acting, as a result of a matter contained in this publication. All or part of this publication may be reproduced without further permission, provided the source is acknowledged.

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.

Please note that this is not a peer-reviewed report but has formed part of a submission made by the Department of the Environment, Community and Local Government to the European Commission Technical Sub-Group on Noise for the Marine Strategy Framework Directive. This Technical Sub-Group confirmed that the report fulfils the requirements from Ireland of the work package (M1 - b), i.e. it is work towards the establishment of a common noise register.

EPA STRIVE PROGRAMME 2007–2013

Published by the Environmental Protection Agency, Ireland

PRINTED ON RECYCLED PAPER



ISBN: 978-1-84095-461-6

Price: Free

09/12/40

ACKNOWLEDGEMENTS

This report is published as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013. The programme is financed by the Irish Government under the National Development Plan 2007–2013. It is administered on behalf of the Department of the Environment, Community and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to thank those collaborators who made this project possible. The provision of metadata by the Petroleum Affairs Division of the Department of Communications, Energy and Natural Resources, Ireland, is acknowledged.

They would also like to thank the project Steering Committee: Lisa Sheils, Mary Meacle, Comm. Mark Mellet, Stephen Robinson and Michael Hanrahan for their input on the project.

Details of Project Partners

Suzanne Beck

Marine Biodiversity Research Group
Marine & Freshwater Research Centre
Galway–Mayo Institute of Technology
Dublin Road
Galway
Ireland
Tel.: +353 91 742524
Email: Suzanne.Beck@gmit.ie

Ian O'Connor

Marine Biodiversity Research Group
Dept. of Life and Physical Sciences
Galway–Mayo Institute of Technology
Dublin Road
Galway
Ireland
Tel.: +353 91 742296
Email: ian.oconnor@gmit.ie

Joanne O'Brien

Department of Life Sciences
Galway–Mayo Institute of Technology
Dublin Road
Galway
Ireland
Tel.: +353 91 742277
Email: joanne.obrien@gmit.ie

Simon Berrow

Marine Biodiversity Research Group
Dept. of Life and Physical Sciences
Galway–Mayo Institute of Technology
Dublin Road
Galway
Ireland
Tel.: +353 91 742296
Email: simon.berrow@gmit.ie

Table of Contents

<u>Disclaimer</u>	<u>ii</u>
<u>Acknowledgements</u>	<u>iii</u>
<u>Details of Project Partners</u>	<u>iv</u>
<u>Executive Summary</u>	<u>vii</u>
<u>1 Introduction</u>	<u>1</u>
<u>2 Materials and Methods</u>	<u>4</u>
<u>2.1 Data Acquisition</u>	<u>4</u>
<u>2.2 Seismic Exploration 2000–2011</u>	<u>5</u>
<u>2.3 Intensity of Sound in Seismic Exploration</u>	<u>5</u>
<u>3 Results</u>	<u>6</u>
<u>3.1 Seismic Exploration 2000–2011</u>	<u>6</u>
<u>3.2 Intensity of Sound in Seismic Exploration</u>	<u>8</u>
<u>4 Discussion</u>	<u>23</u>
<u>References</u>	<u>25</u>
<u>Acronyms</u>	<u>27</u>
<u>Appendix 1</u>	<u>28</u>

Executive Summary

Anthropogenic noise is now recognised as a significant pollutant in the marine environment and there is a growing interest from the scientific community, policy makers and the general public in the effects of anthropogenic noise on marine life.

The Marine Strategy Framework Directive (MSFD) has developed criteria under Descriptor 11 Noise to define, identify and quantify anthropogenic sound sources, encompassing both low- and mid-frequency impulsive sound (Indicator 11.1.1) and low-frequency continuous sound (Indicator 11.2.1). This report is part of a project on the assessment and monitoring of ocean noise in Irish waters, addressing both Indicators, and is a key delivery on behalf of Ireland meeting obligations under the MSFD. Indicator 11.1.1 addresses noise sources from seismic surveys, sonar, piledriving, acoustic deterrents and the use of explosives. Seismic surveying is the primary technique used in the search for oil and natural gas reserves and is a major sound source of concern when assessing low- and mid-frequency impulsive sound in Irish waters.

1. This report aims to assess the pressure of impulsive low- and mid-frequency sounds across the Irish Exclusive Economic Zone (EEZ) by quantifying seismic activity at specific geographic locations within Irish waters, helping Ireland to fulfil requirements under the MSFD. Details of seismic surveys conducted in waters under Irish jurisdiction from 2000 to 2011 were obtained from the Petroleum Affairs Division (PAD) of the Department of Communications, Energy and Natural Resources.
2. To quantify seismic activity, a methodology incorporating *bang days*, as proposed by the Technical Sub-Group of MSFD Descriptor 11, was used. Bang days were defined as “*days in which data from seismic surveying were acquired*”, assessed in cell blocks of 10' latitude by 12' longitude.
3. To investigate the development of seismic survey

equipment, surveys conducted from 2000 to 2011 in Irish waters were categorised based on the volume of the air-gun array in cubic inches. Larger volume arrays are deemed likely to produce louder noise than smaller volume arrays and so volume was used here as a proxy for noise level.

4. Between the years 2000 and 2011, a total of 44 seismic surveys were conducted in waters under Irish jurisdiction. The number of active offshore authorisations has been steadily increasing since 2002, reaching a total of 42 active authorisations in 2011. The year 2011 also reported the greatest number of granted offshore authorisations, indicating a potential rise in seismic activity in the coming years.
5. Noise maps were generated across the years 2000–2011 for bang days and array volume. Analyses of seismic exploration between the years 2000 and 2011 revealed specific areas of interest to the oil and gas industry, namely quadrants Q11, Q12, Q18, Q19, Q25, Q27, Q43, Q48, Q49, Q50 and Q57. The most commonly used array volume in Irish waters between 2000 and 2011 was >3,000–4,000 cubic inches. The emergence of larger volume air-gun arrays occurred in 2007 and, in 2011, array volumes used in seismic surveying exceeded 8,000 cubic inches.

This report has highlighted specific geographical areas with a greater frequency of seismic exploration and additionally highlighted specific geographical areas that have been surveyed using the larger volume arrays. This report was completed as part of a research project (2011-W-MS-6) undertaken by Galway–Mayo Institute of Technology (GMIT), which was funded by the Irish Environmental Protection Agency (EPA) Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013 and by the Irish Government on behalf of the Department of the Environment, Community and Local Government.

1 Introduction

Ocean noise has always existed, both in natural and biological forms. Undoubtedly, due to its recent and uncontrolled character, the substantial introduction of artificial sound sources at a large scale has become a threat to this balance. Anthropogenic noise is now recognised as a significant pollutant in the marine environment and there is a growing interest from the general public in the effects of anthropogenic noise on marine life. As sound travels very efficiently in water, the affected areas, depending on emitted frequency, can be vast. Low-frequency sounds can travel hundreds or even thousands of kilometres (Richardson et al., 1995) from the source, much further than high-frequency sound. It is due to these acoustic properties that the Marine Strategy Framework Directive (MSFD) has developed criteria under Descriptor 11 to define, identify and quantify these sound sources, encompassing both low- and mid-frequency impulsive sound (Indicator 11.1.1) and low-frequency continuous sound (Indicator 11.2.1).

Descriptor 11 *Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.*

Indicator 11.1.1 *Distribution in time and place of loud, low and mid frequency 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 1 $\mu\text{Pa}^2\cdot\text{s}$) or as peak sound pressure level (in dB re 1 $\mu\text{Pa}_{\text{peak}}$) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1).

Indicator 11.1.1 of Descriptor 11 under the MSFD (Tasker et al., 2010) addresses noise sources from seismic surveys, piledriving, acoustic deterrents, and the use of explosives. Seismic surveying is the primary

technique used in the search for oil and natural gas reserves and is a major sound source of concern when assessing low- and mid-frequency impulsive sound in Irish waters. Seismic exploration uses pulses of compressed air to create impulsive broadband sound waves of ultra-short duration with high peak source levels (Nowacek et al., 2007). Air guns are commonly grouped into clusters or arrays, and can be mounted on a vessel or arranged in a device, towed along by a vessel. During operation, noise is emitted with source levels of 220–255 dB re 1 mPa peak at 1 m (Nowacek et al., 2007); the acoustic energy is strongest between 10 and 120 Hz but high-frequency sound of up to 100 kHz has been measured at low amplitudes. The waves are directed downwards and, when reflected back up from the seabed, are detected by hydrophones; this information can then be analysed to assess the location and size of potential oil and natural gas deposits. A variety of geophysical equipment is available for use in seismic surveys, including sparkers, boomers, pingers, chirp sonar and air guns. Sparkers, boomers and chirp sonar are all high-frequency seismic devices producing sounds between 0.5 and 12 kHz, with source levels of 204–210 dB (rms) re 1 μPa at 1 m (sparkers and boomers) and 210–230 dB re 1 μPa at 1 m (chirp sonar) (OSPAR, 2009). Air guns are the most frequently used apparatus; they generate predominantly low-frequency sound and are the main source of concern for Ireland under Indicator 11.1.1.

Seismic surveys are temporary and spatially localised in nature; however, noise from a single survey can filter through vast expanses of ocean. Sound emitted from a seismic survey conducted in the north-west Atlantic spanned a region of almost 160,935 km² (100,000 square miles), raising noise levels 100 times higher than normal ambient noise levels, continuously for days at a time (IWC, 2005). Furthermore, reverberations can cause ‘ringing’, continuously elevating background noise levels for much longer than the ultra-short duration noted for seismic air-gun sounds (Guerra et al., 2011). Reverberations alone

were reported to increase background noise levels up to 128 km away from the source for one survey off the Alaskan North Slope (Guerra et al., 2011).

The next few decades will see increasing levels of offshore industrial development that could lead to increased amounts of noise pollution in the oceans. Ireland is reported to import more than 80% of its gas requirements, increasing the pressure to discover indigenous natural gas and oil deposits. In the past decade, there has been a substantial rise in licence applications for offshore exploration and developments in Irish waters and, according to the Irish Offshore Strategic Environmental Assessments 3 and 4 produced by the Petroleum Affairs Division (PAD) of the Department of Communications, Energy and Natural Resources, seismic surveying will reach a likely maximum of 49,000 km for two-dimensional (2D) and 28,000 km² for three-dimensional (3D) surveys between 2010 and 2016 in the Rockall Basin alone (PAD, 2008). Additionally, in the Irish and Celtic Seas, licensing has been on an 'open-door' basis and it is likely that a maximum of some 100,000 km for 2D and 30,000 km² for 3D will be surveyed between 2011 and 2020 (PAD, 2011).

Anthropogenic noise has been documented to affect a range of marine life (OSPAR, 2009). A number of reviews have investigated research on marine mammals and, in particular, cetaceans (Gordon et al., 2004; Nowacek et al., 2007; Southall et al., 2007; Weilgart, 2007). In 2005, the International Whaling Commission's Scientific Committee concluded that increased sound specifically from seismic surveys was 'cause for serious concern' (IWC, 2005). As cetaceans rely on sound as their primary sense for orientation, navigation, foraging and communication, anthropogenic sounds can impact in a number of ways and this is dependent on sound frequency and intensity. There may be further long-term consequences due to chronic exposure, and sound can indirectly affect animals due to changes in the accessibility of prey, which may also suffer the adverse effects of acoustic pollution (Richardson et al., 1995). These damages could significantly impair the conservation of already endangered species that use acoustically contaminated areas for migratory routes, reproduction, and feeding.

Direct effects of seismic exploration as part of the oil and gas industry include changes in cetacean behaviour, distribution and a distinct range of physical injuries. Stone and Tasker (2006) reported a reduced sighting rate of all cetacean species during periods of large-volume air-gun operation. A temporary shift in masked hearing thresholds has been reported for the beluga whale (*Delphinapterus leucas*) after exposure to seismic air-gun sounds (Finneran et al., 2002) and changes in vocalisation behaviour have been noted for a number of cetacean species including bowhead whales (*Balaena mysticetus*) and common dolphins (*Delphinus delphis*) in response to seismic exploration (Goold, 1996; Blackwell et al., 2008). While there is higher frequency energy in the seismic pulses, the vocalisations and estimated hearing range of baleen whales overlap with the highest peaks of acoustic energy of air-gun sounds and, consequently, these animals may be more affected by this type of disturbance than toothed whales (Southall et al., 2007). There are 24 species of cetaceans known to occur in Irish waters, six of which are baleen whales (O'Brien et al., 2009). The fin whale (*Balaenoptera physalus*) is the most commonly observed large baleen whale in Irish waters. Research elsewhere on this species has reported changes in distribution and an avoidance of potential wintering grounds in response to seismic air-gun activity (Castellote et al., 2009). Results from a study conducted by Gedamke et al. (2010) suggested that baleen whales could be susceptible to a temporary threshold shift at 1 km or further from seismic surveys. Past research has recorded avoidance reactions from humpback whales (*Megaptera novaeangliae*) to seismic exploration (McCauley et al., 1998). Studies are ongoing in Australia aiming to further understand and analyse the behavioural response of humpback whales to seismic surveys (Cato et al., 2011).

The acoustic properties of air-gun sounds emitted from seismic exploration and what is known of fish auditory thresholds indicate that marine fish species can hear air-gun sounds. Behavioural changes and pathological and indirect effects have been reported in a number of fish species in response to noise from seismic exploration. Irish waters host many commercially important marine fish species. Indirect effects on fisheries have been reported, with a decrease in catch

per unit effort of 52% in hook and line fishing of rockfish species along the Californian coast (Skalski et al., 1992) and declines in trawl catches of both cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) in zones exposed to seismic air-gun firing in the Barents Sea (Engas et al., 1996). In the Norwegian Sea, Slotte et al. (2004) confirmed a change in depth distribution of blue whiting in the immediate vicinity after air-gun operation, while fish abundance increased in areas 30–50 km from the source. Similarly, Pearson et al. (1992) reported shifts in vertical distribution, changes in behaviour and the occurrence of startle and alarm responses of marine fish to seismic air-gun pulses along the Californian coast. Cod, haddock and blue whiting are all commercially important fish for Ireland and these results may indicate the types of responses that could occur when exposed to anthropogenic noise from seismic surveying in Irish waters.

The Norway lobster (*Nephrops norvegicus*) is an important invertebrate in the Irish waters fishery industry, with average annual landings of 18,327 t between 2008 and 2010 (Marine Institute, 2011). The effects of noise on marine invertebrates have been studied to a lesser extent. It is likely that marine invertebrates may be most sensitive to the vibrational component of sound and these statocyst organs provide a means of vibration detection (NFS, 2012). André et al. (2011) recently documented fatal pathological impacts on the sensory hair cells of the statocysts in cephalopods. The leatherback turtle (*Dermochelys coriacea*) is also considered a member of the Irish marine fauna and part of Ireland's natural heritage (Doyle, 2007). Few studies have been conducted on the effect of noise on marine turtles. Behavioural changes have been reported but it is considered unlikely that sea turtles are more sensitive

to noise emitted from seismic exploration than are cetaceans (DFO, 2004).

The current challenge is to implement technological developments that combine the good environmental status of the oceans with the interests of the industry. The potential increase in offshore industrial development will not affect all areas equally but specific regions where offshore exploration interest is high. The power of seismic air guns has increased over time as greater depths are explored and, as a result, noise emitted by seismic exploration has increased. Larger volume arrays generally contain more air guns and so have a higher cumulative source level and are thus of a greater concern in the assessment of noise on the marine environment. Potential effects might not be proportionate to pollution levels due to variation in sound propagation and, most importantly, due to the distribution of marine life that is sensitive to sound. At present, mitigation measures devised by the National Parks and Wildlife Service (NPWS) for the protection of marine mammals during acoustic sea-floor surveys in Irish waters are in place (NPWS, 2007). Guidelines state that Marine Mammal Observers (MMOs) are required to be present on board the survey vessel to conduct observations 30 min before the onset of operation in waters of 200 m or less, and 60 min in waters greater than 200 m. A soft start is recommended after the area has been confirmed clear of cetaceans, while exclusion zones of 1 km should be in operation. The next step is an assessment and review of current available data sets to assess and quantify the level of seismic activity at specific geographic locations within Irish waters. This will assess the pressure of impulsive low- and mid-frequency sounds across the Irish Exclusive Economic Zone (EEZ) and will facilitate the Irish Government to fulfil Ireland's requirements under the MSFD.

2 Materials and Methods

2.1 Data Acquisition

Details of seismic surveys conducted in waters under Irish jurisdiction from 2000 to 2011 were obtained from the PAD of the Department of Communications, Energy and Natural Resources. Shape files of 2D and 3D seismic surveys each year and a shape file of the authorisations granted since 2000 were provided as well as specific data for each seismic survey, including Survey ID, Start Date, End Date, Acquisition Dates, Source Type (including volume of array in cubic inches), Total Length of 2D Line (km), Total 3D Area (km²), Quads Covered and Cell Blocks Covered (for full details of data provided, see [Appendix 1](#)).

The PAD divides the currently designated Irish continental shelf into quadrants of 1° latitude by 1° longitude and cell blocks of 10' latitude by

12' longitude ([Fig. 2.1](#)). It was deemed that the division of the designated area into cell blocks defined by the PAD was a suitable spatial scale required for analysis of seismic activity under the MSFD Indicator 11.1.1. This cell size was also used for analysis of seismic activity in the UK and will allow for comparison between these two Member States and the assessment of trans-boundary effects. Additionally, it was deemed appropriate to report on seismic activity occurring outside the Irish EEZ and the currently proposed MSFD boundary but within the currently designated Irish continental shelf in which the PAD authorises seismic exploration. Both the MSFD boundary and the designated Irish continental shelf are shown in the seismic survey figures in [Chapter 3](#) to facilitate data interpretation and to assess noise emissions across geographical regions.

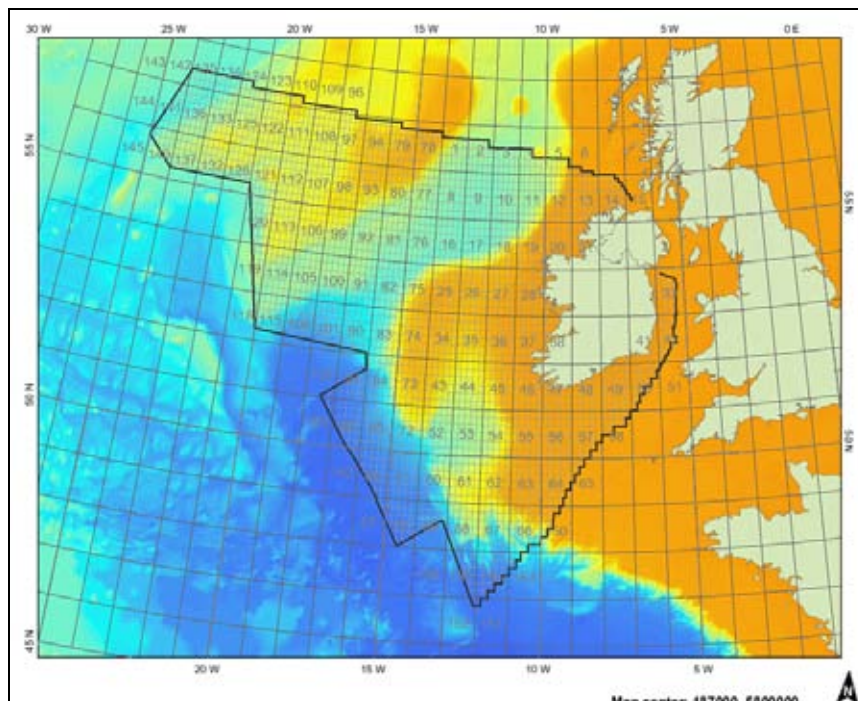


Figure 2.1. Map of the currently designated Irish continental shelf showing numbered quadrants of 1° latitude by 1° longitude and cell blocks by 10' latitude by 12' longitude contained within, used for the analysis of seismic surveys under Indicator 11.1.1 low- to mid-frequency impulsive sound. © DCENR PAD 2012, reproduced with permission.

2.2 Seismic Exploration 2000–2011

The raw data required reformatting as surveys differed in the amount of available detailed information and, as such, methodologies had to be in place to standardise the data set. Bang days were defined as ‘days in which data from seismic surveying were acquired’. Bang days were determined by the data acquisition dates provided by the PAD. Where acquisition dates were not available, dates with seismic data acquisition were assumed for the entire survey duration. This is likely to be an overestimation of bang days, although instances of missing acquisition dates were minimal (7%) and so results obtained from this analysis are thought to be reliable and accurate. To determine the extent of seismic surveying in Irish waters and the locations under greatest surveying pressure, noise maps were generated across the years 2000–2011 through the ArcGIS (version 9.3) mapping software. Methodologies applied by the UK for the geographical representation of bang days were reviewed and developed. If a survey spanned more than one cell block, then bang days per block were estimated as the total number of bang days divided by the total number of blocks for which the survey applied for/spanned. As reported by the UK, this is likely to be an underestimation of survey effort for an individual cell block as most seismic surveys will occur in more than one cell block per day. The MSFD Good Environmental Status (GES) Technical Sub-Group on Underwater Noise and other forms of energy (Van der Graaf et al., 2012) on the assessment of noise from seismic exploration generated noise maps on the basis

that one bang day turns the cell block red. To further develop this method, it was decided to display the total bang days per cell block in groupings of 0, >0–0.5, >0.5–1.0, >1.0–2.5, >2.5–5.0, >5.0. Bang days per year were calculated as the sum of bang days across all surveys conducted within that year. Similarly, bang days across the entire study period were summed to create a noise map for 2000–2011. This scale was chosen on the basis of results from the calculated bang days from waters under Irish jurisdiction and may not represent the best categories for other Member States.

2.3 Intensity of Sound in Seismic Exploration

To investigate the development of seismic survey equipment and techniques, surveys conducted from 2000 to 2011 in Irish waters were categorised based on the volume of the air-gun array (cubic inches), which is used here as a proxy for sound source level. Noise maps were generated through the ArcGIS mapping software for each year; where more than one survey covered a cell block, the mean volume of the air-gun array used in the cell block was displayed. Categories were defined as 0, >0–1,000, >1,000–2,000, >2,000–3,000, >3,000–4,000, >4,000–5,000, >5,000–6,000, >6,000–7,000, >7,000–8,000 and >8,000. This scale was chosen on the basis of summary results from the cubic inches of air-gun arrays used in seismic surveys in waters under Irish jurisdiction and may not represent the best categories for other Member States.

3 Results

3.1 Seismic Exploration 2000–2011

Between the years 2000 and 2011, a total of 44 seismic surveys were conducted in waters under Irish jurisdiction. Of these, 25 surveys were 2D and 19 were 3D (Fig. 3.1). The duration of 2D surveys during this time ranged from 1 day to 51 days, with an average duration of 18 days. The duration of 3D surveys ranged from 4 days to 100 days, with an average of 31 days. For 2D seismic exploration, 0.05–60 cell blocks were surveyed per day, with an average of 5.77 cell blocks per day. The more localised 3D seismic surveys covered 0.02–19.25 cell blocks per day, with an average of 1.45 cell blocks per day. A summary of bang day data revealed that 2D surveys accounted for 1.49 bang days per survey, with an average of 0.17 bang days per day for the survey duration, and 3D surveys accounted for 4.19 bang days per survey, with an average of 0.22 bang days per day for the survey duration.

Clear peaks in seismic exploration for 2D surveys are evident during 2000 and throughout 2005–2008. Seismic exploration through 3D surveying peaked also during 2000 and again most recently in 2011 (Fig. 3.2).

The number of active authorisations has been steadily increasing since 2002, reaching a total of 42 active offshore authorisations and three active onshore authorisations in 2011 (Fig. 3.3). The year 2011 also reported the greatest number of granted offshore authorisations, indicating a potential rise in seismic activity in the coming years.

Analyses of seismic exploration between the years 2000 and 2011 revealed specific areas of interest to the oil and gas industry, namely quadrants Q11, Q12, Q18, Q19, Q25, Q27, Q43, Q48, Q49, Q50 and Q57 (see Fig. 3.16).

- The year 2000 represented the highest number

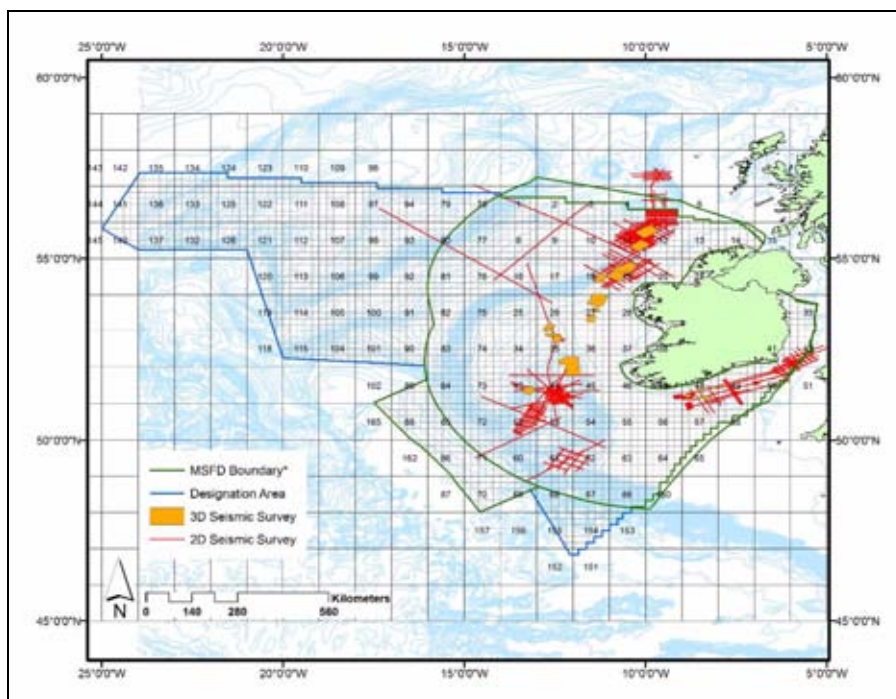


Figure 3.1. Seismic surveys from the year 2000 to 2011 in waters under Irish jurisdiction. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

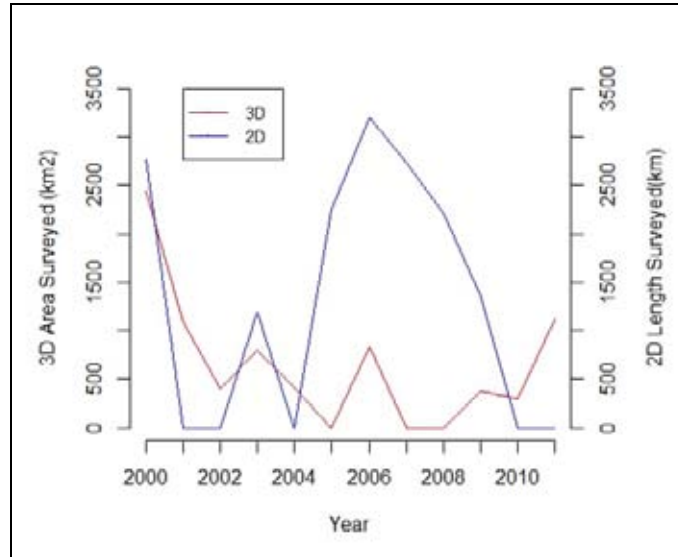


Figure 3.2. Seismic surveys conducted for the period 2000–2011. The total length in kilometres surveyed as part of 2D seismic surveys for each year is shown in blue. The total area in kilometres squared surveyed as part of 3D seismic surveys for each year is shown in red. This does not include two authorisations over the Helvick field in Cell Block 49/9.

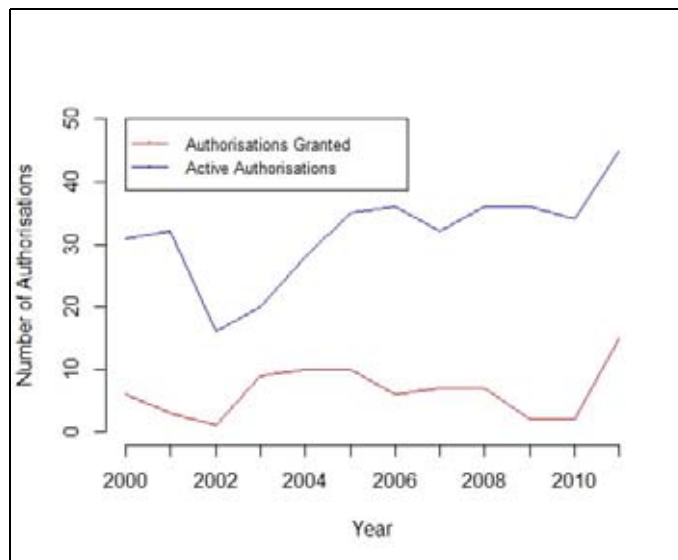


Figure 3.3. Offshore authorisations active for the period 2000–2011. This does not include two authorisations over the Helvick field in Cell Block 49/9. The total number of authorisations granted each year is shown in red. The total number of active authorisations for each year is shown in blue.

of surveys and the greatest pressure in terms of number of cells with bang days greater than 5 (indicated by red shading; [Fig. 3.4](#)). During 2000, seismic exploration spanned 88 cell blocks, with surveying focused on quadrants Q18, Q19 and Q27.

- For 2001 and 2002, seismic exploration was more localised, conducting 3D surveys only spanning quadrants Q18, Q19 and Q27 (see [Fig. 3.16](#)).
- Both 2D and 3D surveys were carried out in 2003 with the majority of seismic exploration pressure

in quadrants Q11 and Q12 ([Fig. 3.7](#)).

- The year 2004 focused on 3D surveying and [Fig. 3.8](#) illustrates that this pressure was localised to quadrant Q43.
- In 2005, one large-scale 2D survey was conducted, spanning quadrants Q42, Q48, Q49 and Q50 ([Fig. 3.9](#)).
- During 2006 and 2007, seismic surveying was mostly 2D in nature and geographic spread was greatest in comparison with any other years, with 113 and 285 cell blocks covered, respectively.
- Surveys carried out in 2008 were all 2D and covered quadrants Q48, Q49 and Q57.
- This was followed by mainly 3D seismic exploration during 2009, 2010 and 2011 in quadrants Q26, Q27, Q35, Q48 and Q49 ([Figs 3.13–3.15](#)).

3.2 Intensity of Sound in Seismic Exploration

Analysis of the development of seismic survey equipment between 2000 and 2011 suggests that the volume of air-gun arrays has been increasing through the years ([Fig. 3.17](#)). The majority of air-gun arrays used in waters under Irish jurisdiction during this study period can be grouped into three:

1. 0–2,000 cubic inches;
2. >3,000–4,000 cubic inches; and
3. >8,000 cubic inches.

The most commonly used array volume in Irish waters between 2000 and 2011 was >3,000–4,000 cubic inches.

Results from the analysis of cubic inches of air-gun arrays as a proxy for noise emissions yielded interesting trends across the study period. The

emergence of larger volume air-gun arrays occurred in 2007 and from this year onwards the volume of air-gun arrays used in seismic operations generally has been above the >3,000–4,000 category, the most commonly used volume across the entire period.

Areas of large array usage can be identified as quadrants Q1, Q2, Q3, Q5, Q8, Q9, Q10, Q11, Q12, Q16, Q18, Q19, Q20, Q26, Q27, Q35, Q43, Q44, Q45, Q48, Q49, Q52, Q53, Q54, Q60, Q61, Q62, Q69, Q71, Q76, Q77, Q78, Q90, Q94, Q99 ([Fig. 3.30](#)), although this is largely attributed to one large-scale 2D survey conducted in 2007, spanning 214 cell blocks using a large air-gun array of 7,440 cubic inches ([Fig. 3.25](#)).

The results indicate a possible relationship between the volume of the array and the depths to be explored. Most of the exploration past the shelf edge in deep waters has used air-gun arrays with volumes larger than or equal to the most commonly used air-gun volume category (>3,000–4,000). However, this is also largely based on the large-scale 2D survey conducted in 2007.

Inspection of air-gun array volume used in surveys in much shallower waters indicates a preference for smaller volume arrays, except in the case of quadrants Q48 and Q49. It is known that in these quadrants, which are highlighted as quadrants under considerable seismic pressure in terms of bang days per cell ([Fig. 3.30](#)), much greater depths are being surveyed to further explore and exploit the Kinsale gas field.

It is not possible to discern whether air-gun array volume varies according to the type of seismic survey being conducted (i.e. 2D or 3D), as the years where, on average the largest arrays were used were also those years most likely to have available the latest developments in air-gun technology (2010 and 2011). Results indicate that it is likely that the coming years will see an increase in the volume of air-gun arrays to be used in the exploration for oil and gas.

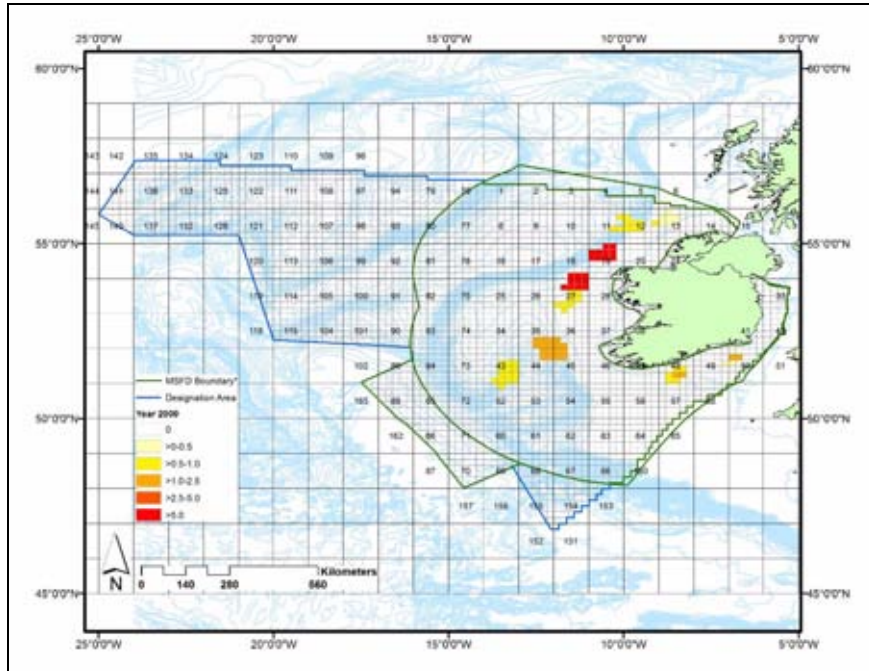


Figure 3.4. Seismic survey pressure in waters under Irish jurisdiction in the year 2000. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

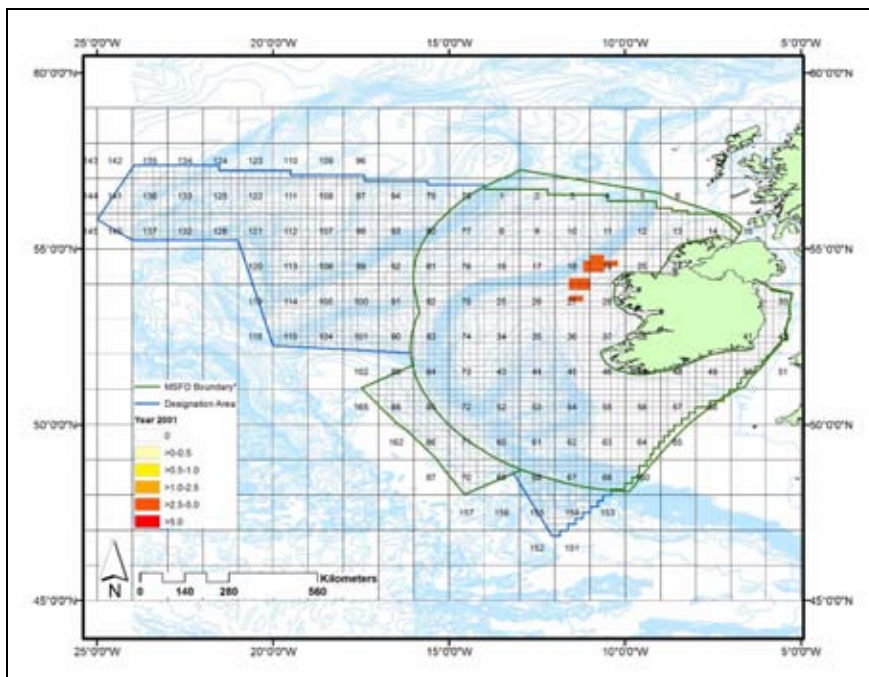


Figure 3.5. Seismic survey pressure in waters under Irish jurisdiction in the year 2001. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

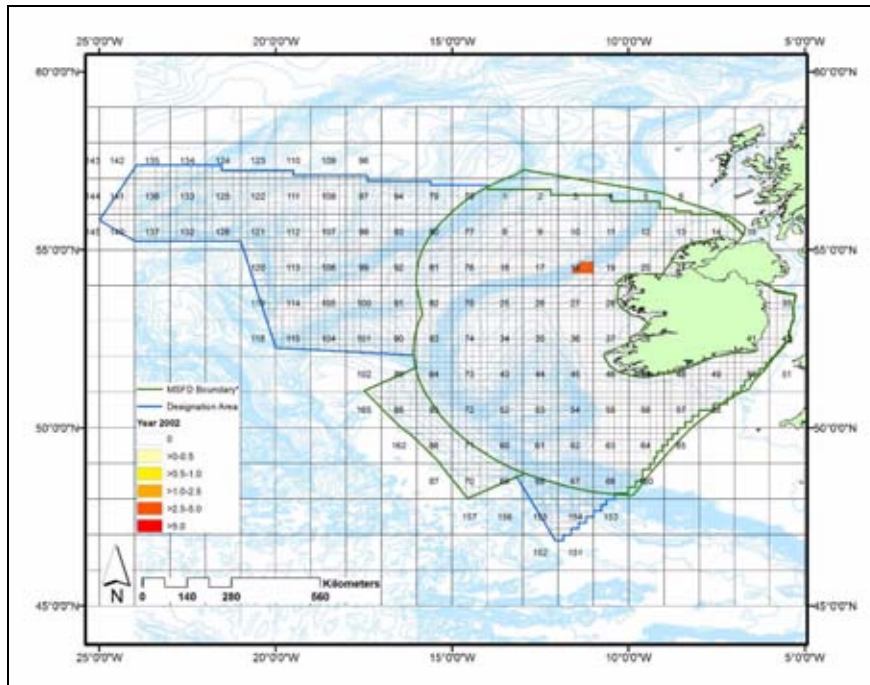


Figure 3.6. Seismic survey pressure in waters under Irish jurisdiction in the year 2002. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

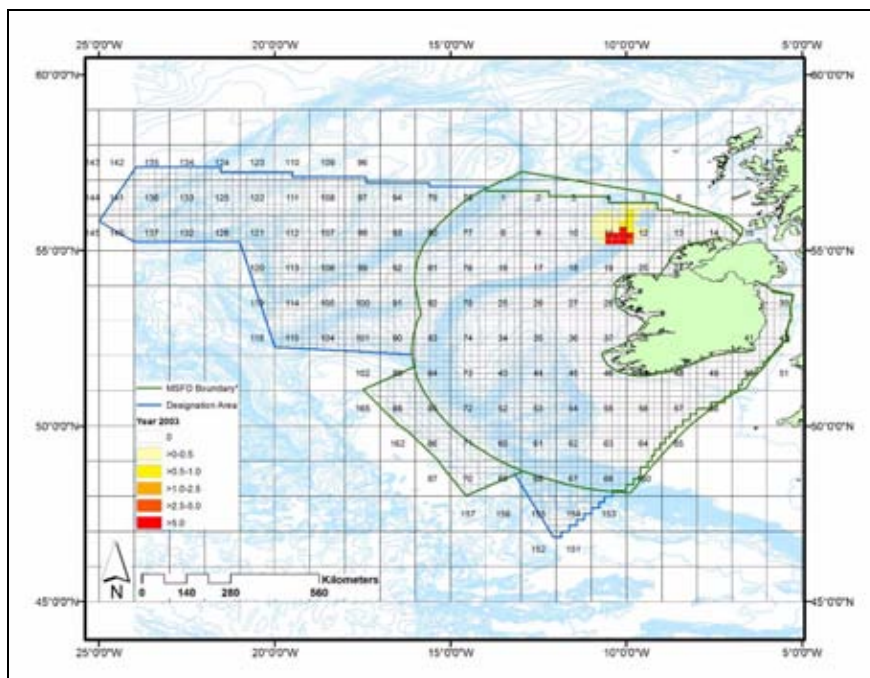


Figure 3.7. Seismic survey pressure in waters under Irish jurisdiction in the year 2003. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

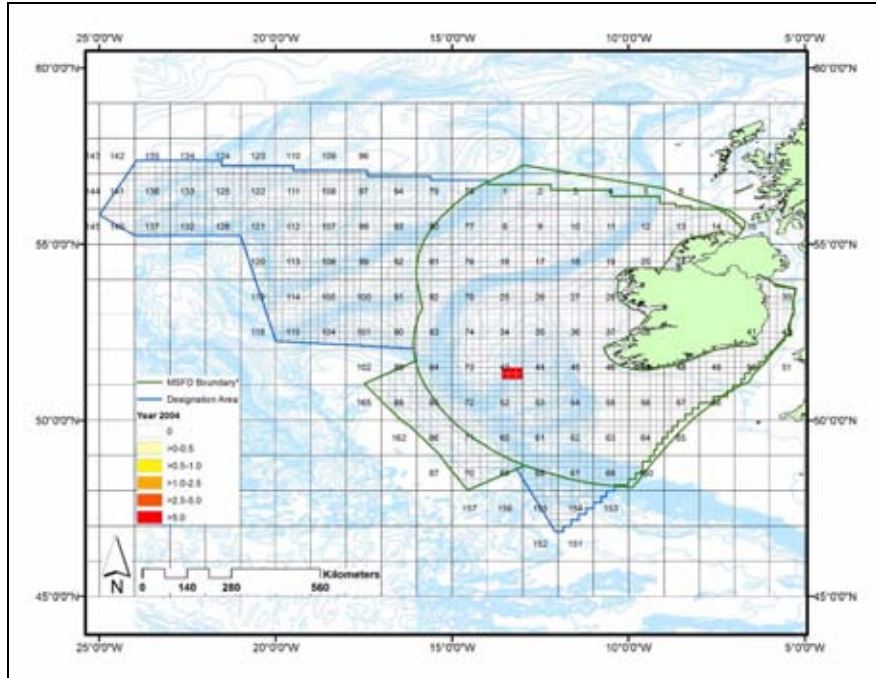


Figure 3.8. Seismic survey pressure in waters under Irish jurisdiction in the year 2004. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

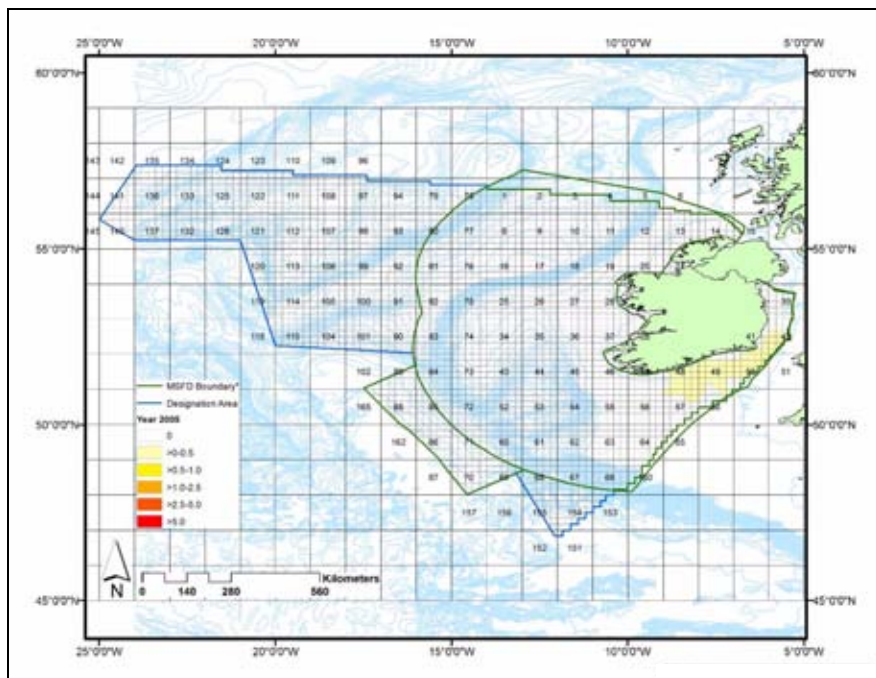


Figure 3.9. Seismic survey pressure in waters under Irish jurisdiction in the year 2005. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

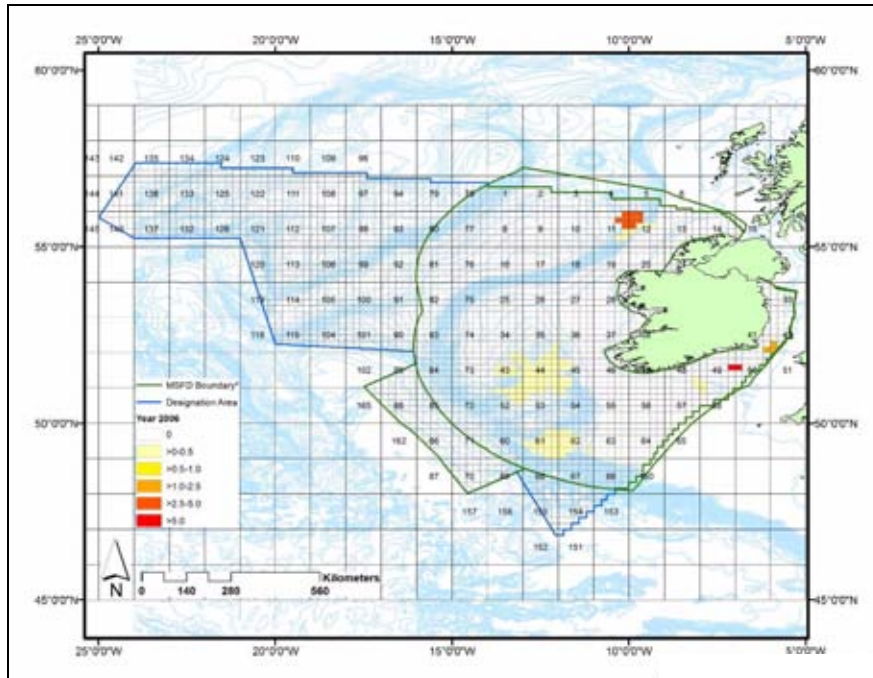


Figure 3.10. Seismic survey pressure in waters under Irish jurisdiction in the year 2006. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

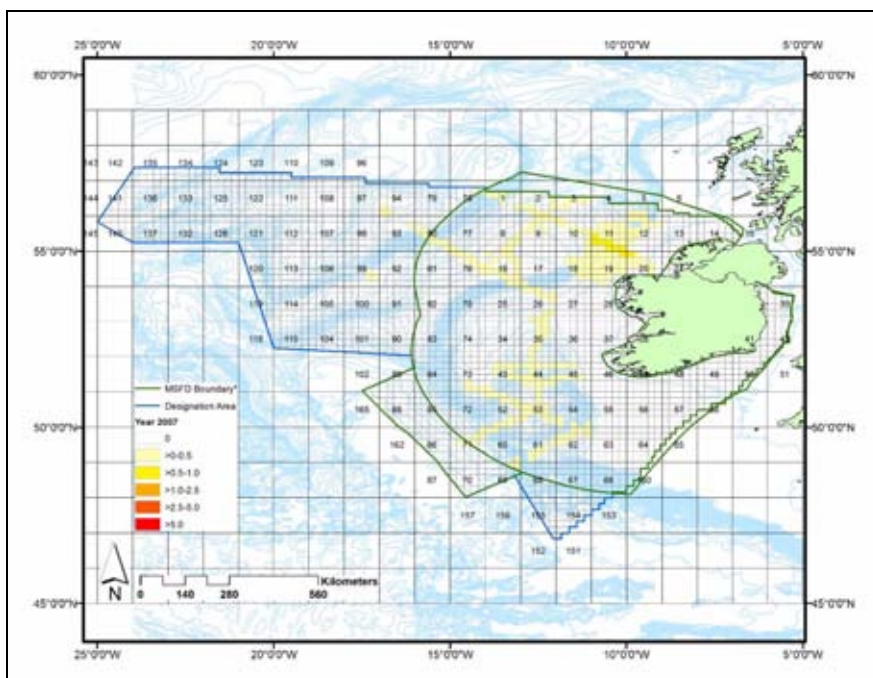


Figure 3.11. Seismic survey pressure in waters under Irish jurisdiction in the year 2007. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

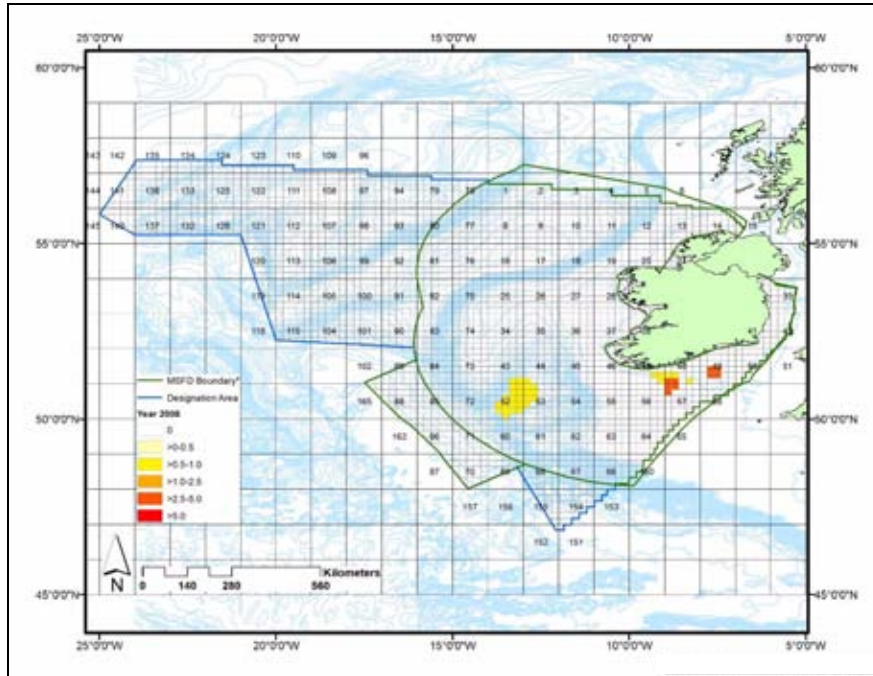


Figure 3.12. Seismic survey pressure in waters under Irish jurisdiction in the year 2008. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

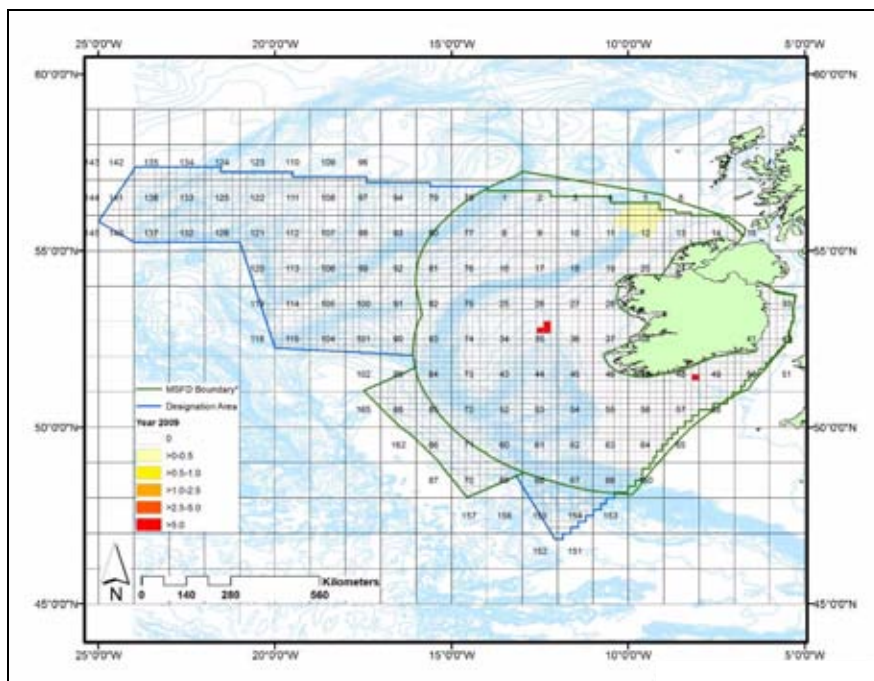


Figure 3.13. Seismic survey pressure in waters under Irish jurisdiction in the year 2009. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

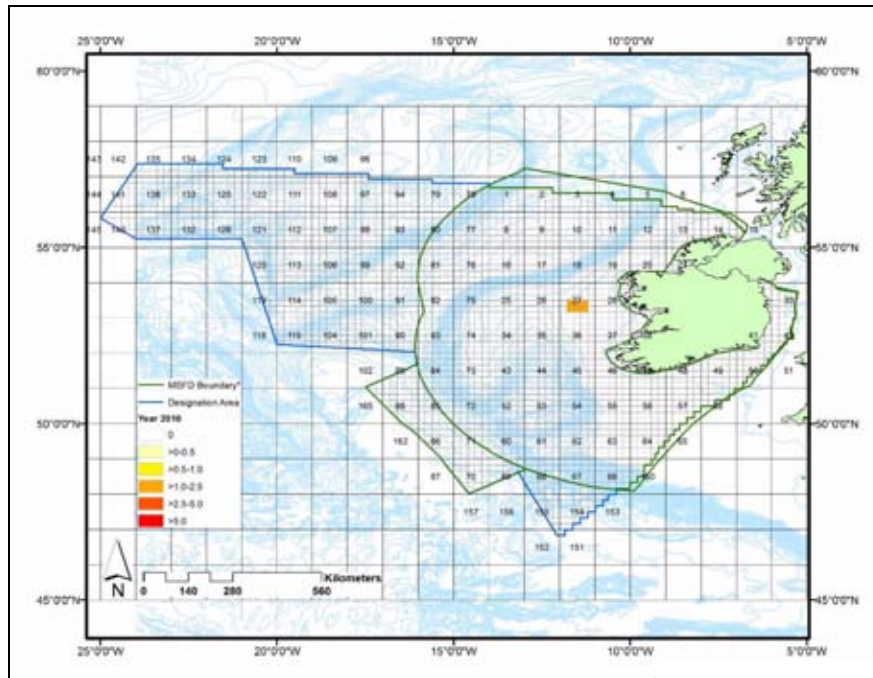


Figure 3.14. Seismic survey pressure in waters under Irish jurisdiction in the year 2010. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

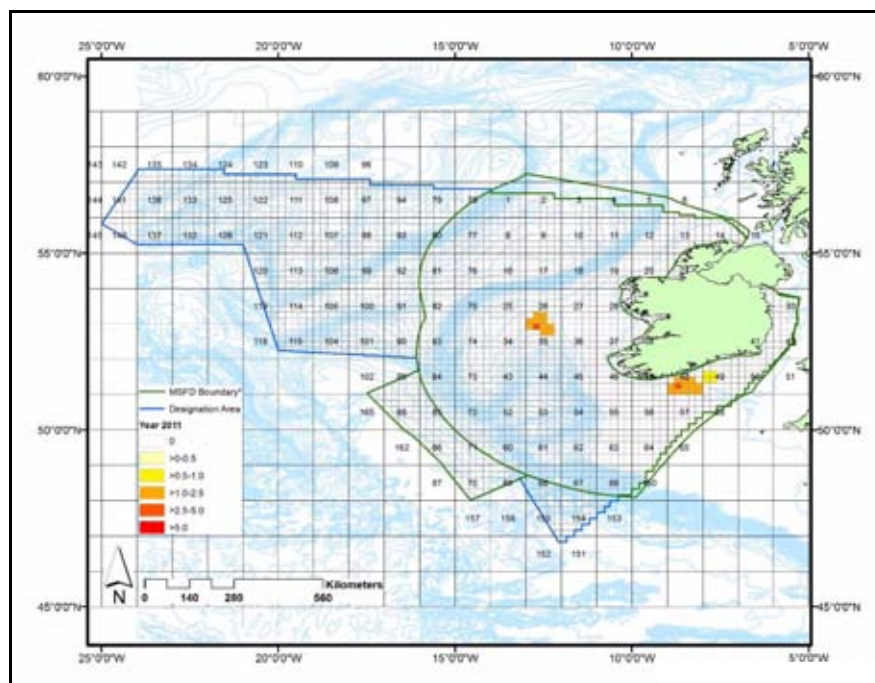


Figure 3.15. Seismic survey pressure in waters under Irish jurisdiction in the year 2011. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

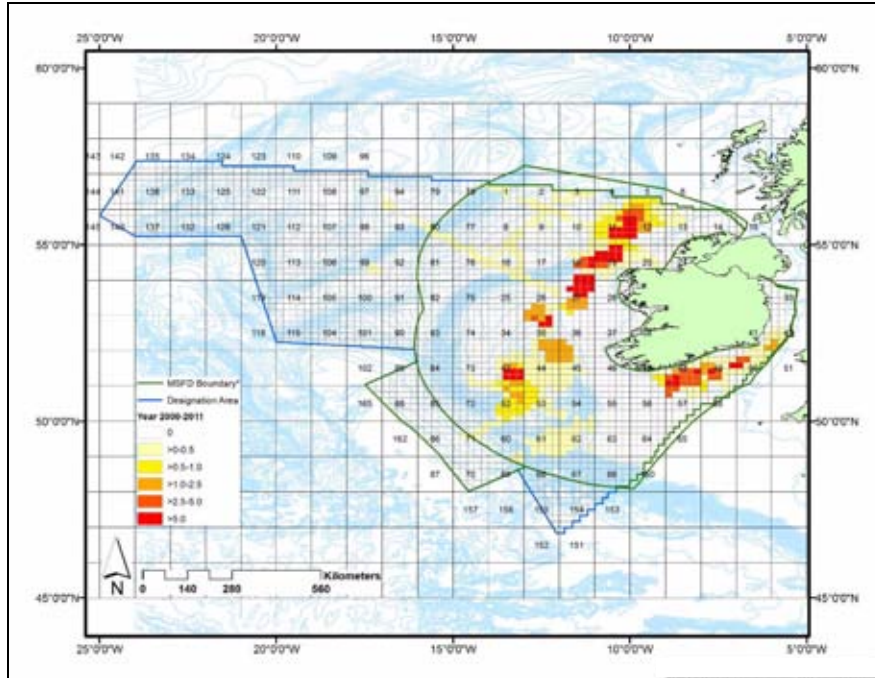


Figure 3.16. Seismic survey pressure in waters under Irish jurisdiction between 2000 and 2011. Bang days, days involving acquisition of seismic data, are shown in a graduated colour scheme, with darker colours representing the greatest number of bang days per cell. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

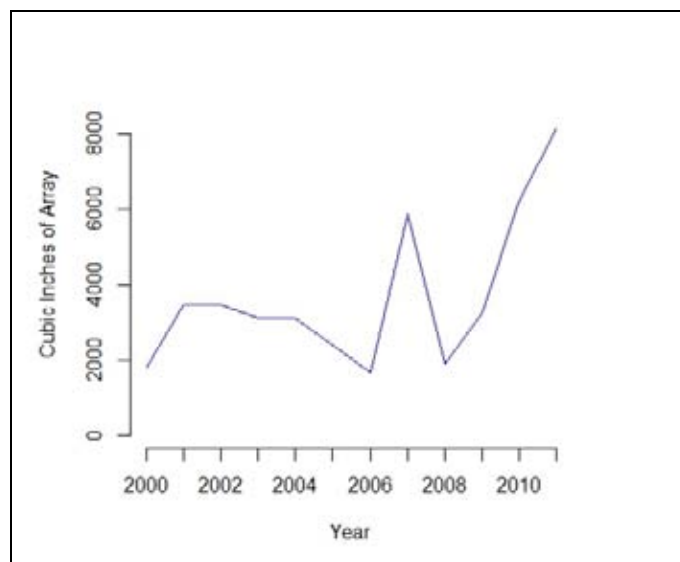


Figure 3.17. Average volume of seismic air gun(s), in cubic inches, used during surveys for each year from the period 2000 to 2011. Note that no data are presented for 2005.

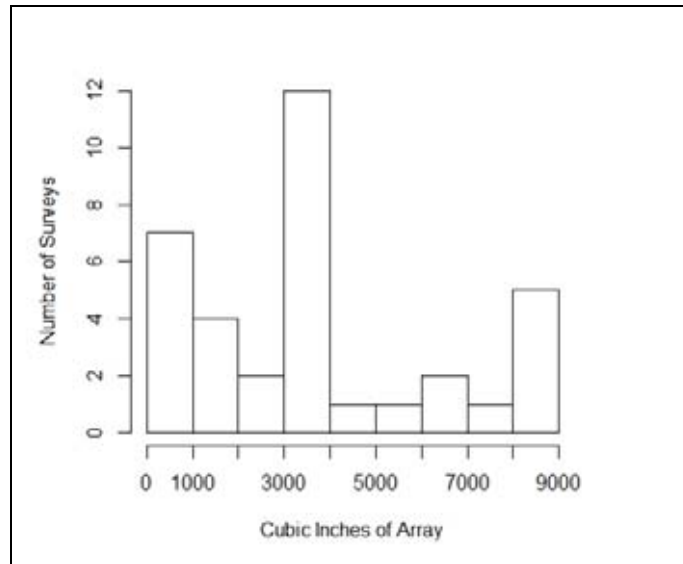


Figure 3.18. Volume of seismic air gun(s), in cubic inches, used during surveys from the period 2000 to 2011 separated into size classes.

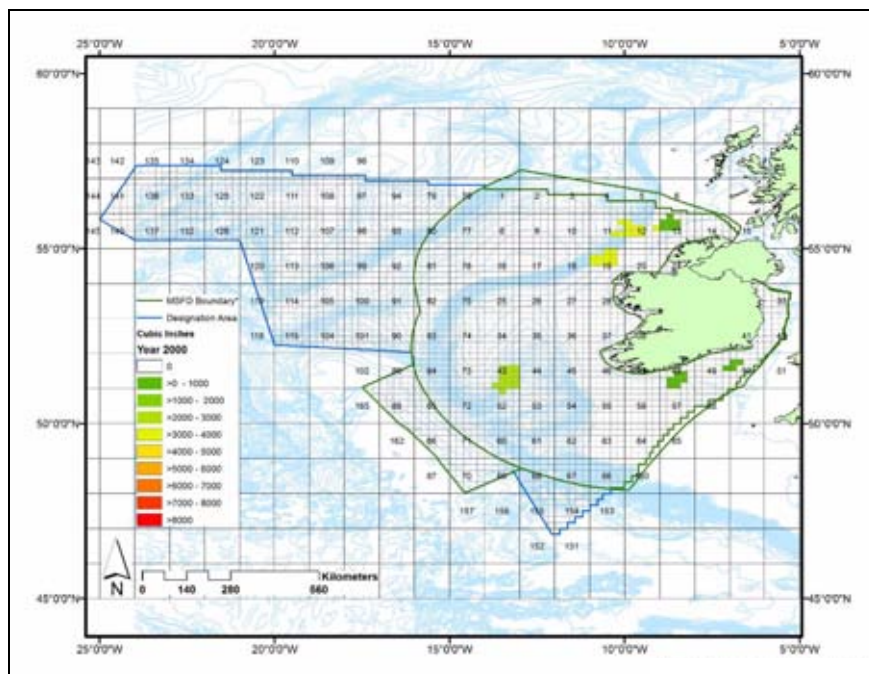


Figure 3.19. Seismic survey pressure in waters under Irish jurisdiction in the year 2000. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

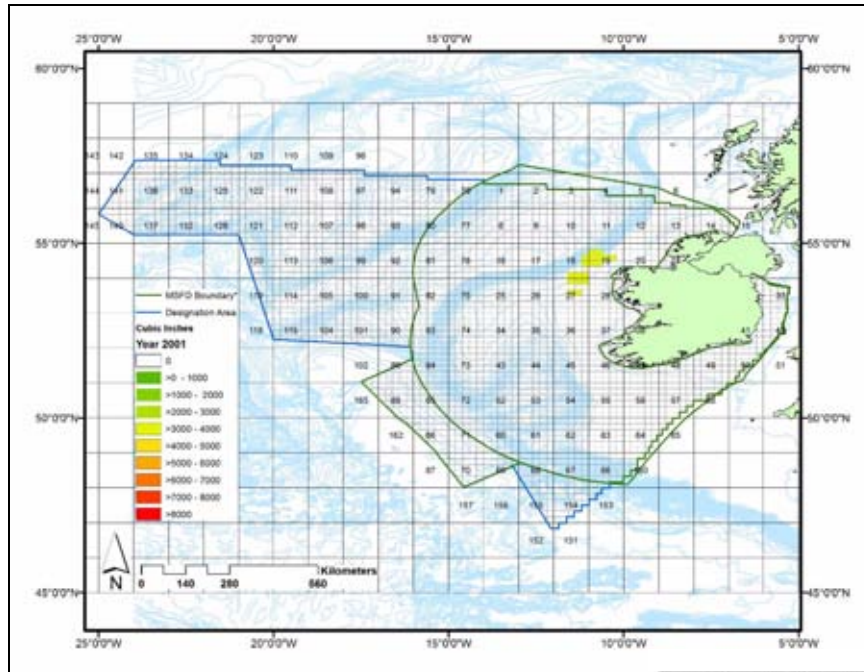


Figure 3.20. Seismic survey pressure in waters under Irish jurisdiction in the year 2001. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

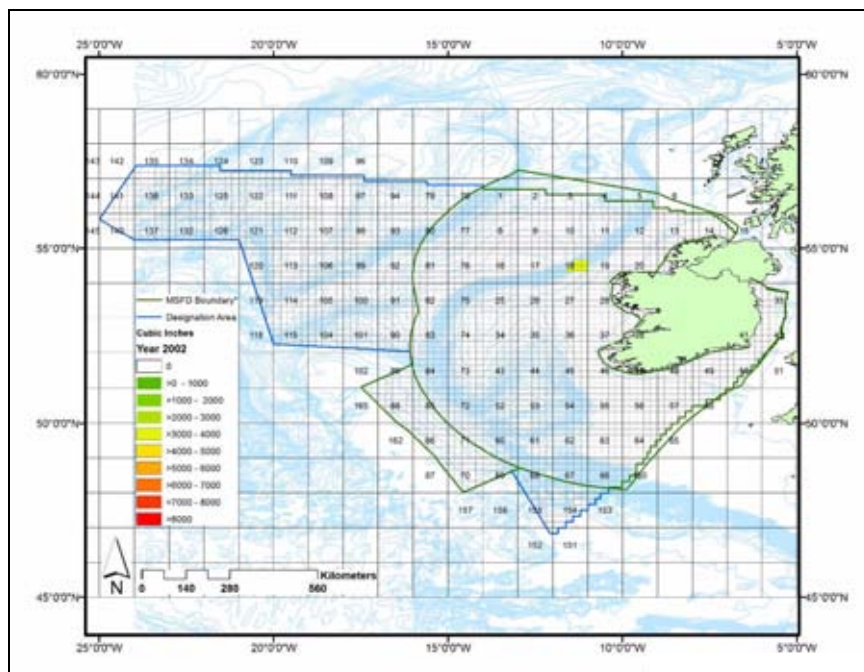


Figure 3.21. Seismic survey pressure in waters under Irish jurisdiction in the year 2002. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

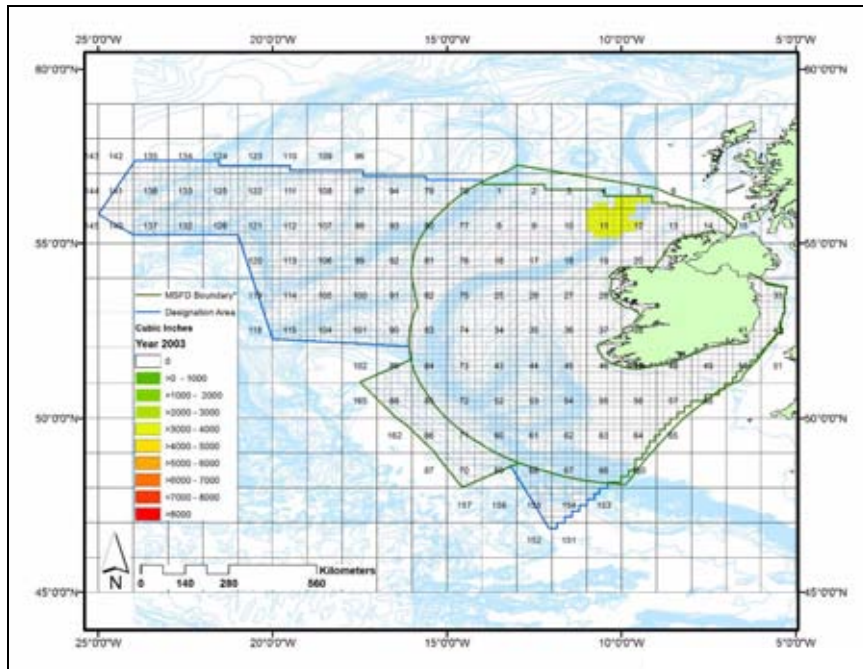


Figure 3.22. Seismic survey pressure in waters under Irish jurisdiction in the year 2003. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

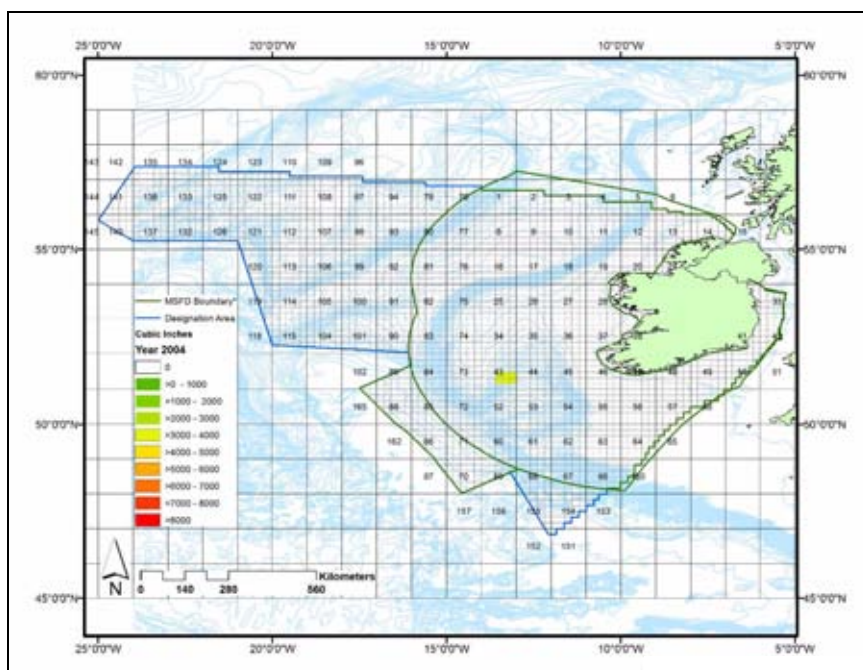


Figure 3.23. Seismic survey pressure in waters under Irish jurisdiction in the year 2004. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

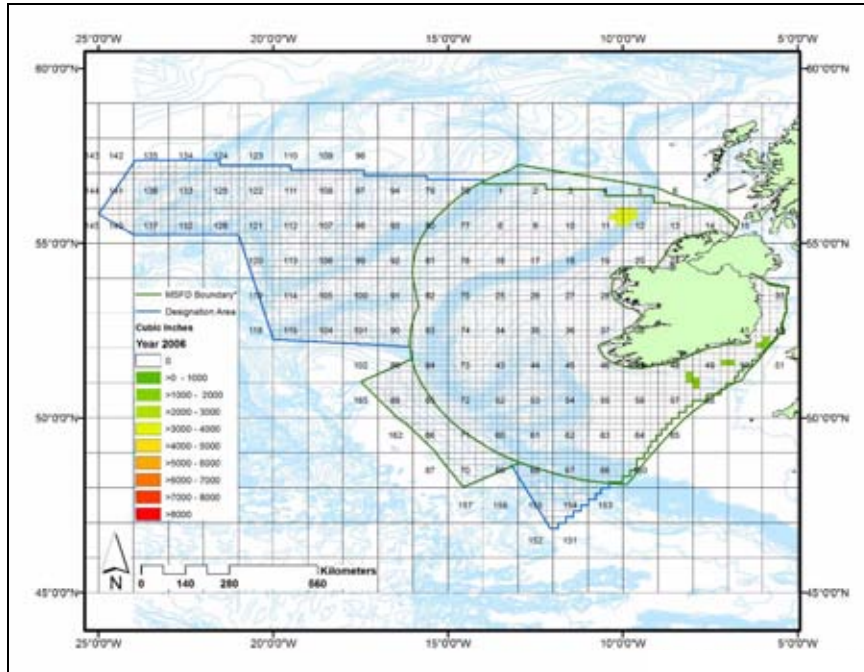


Figure 3.24. Seismic survey pressure in waters under Irish jurisdiction in the year 2006. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

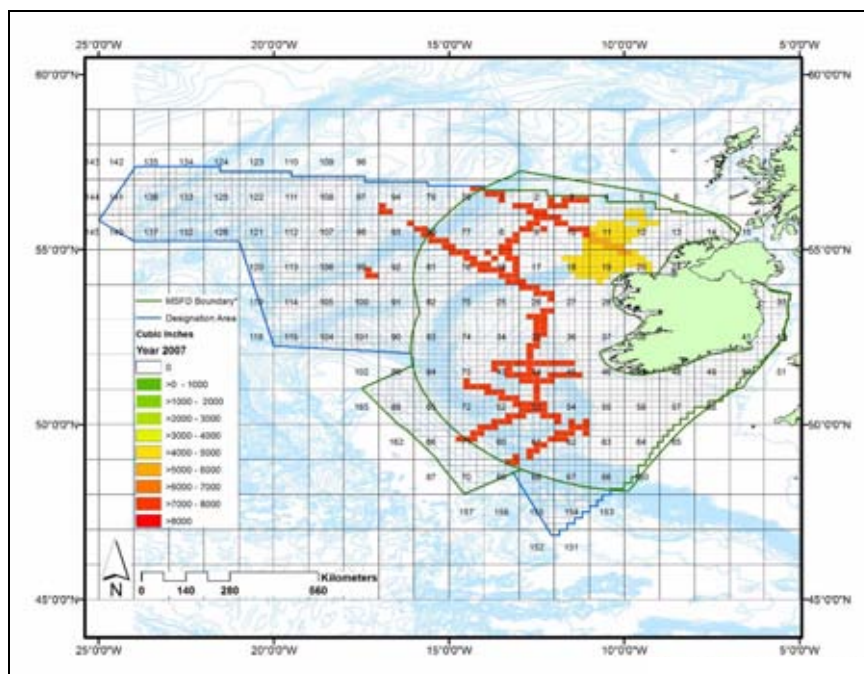


Figure 3.25. Seismic survey pressure in waters under Irish jurisdiction in the year 2007. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

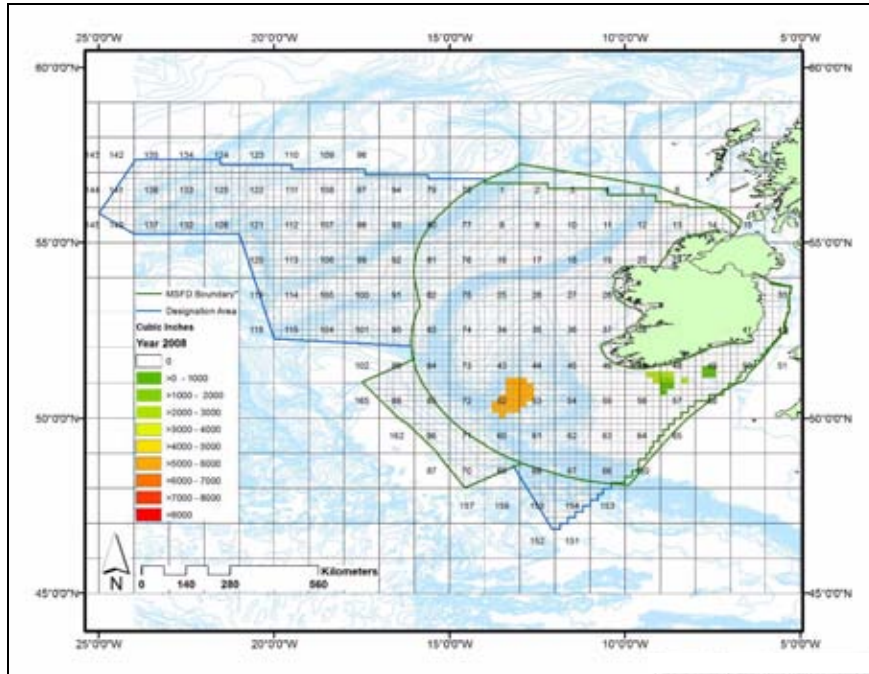


Figure 3.26. Seismic survey pressure in waters under Irish jurisdiction in the year 2008. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

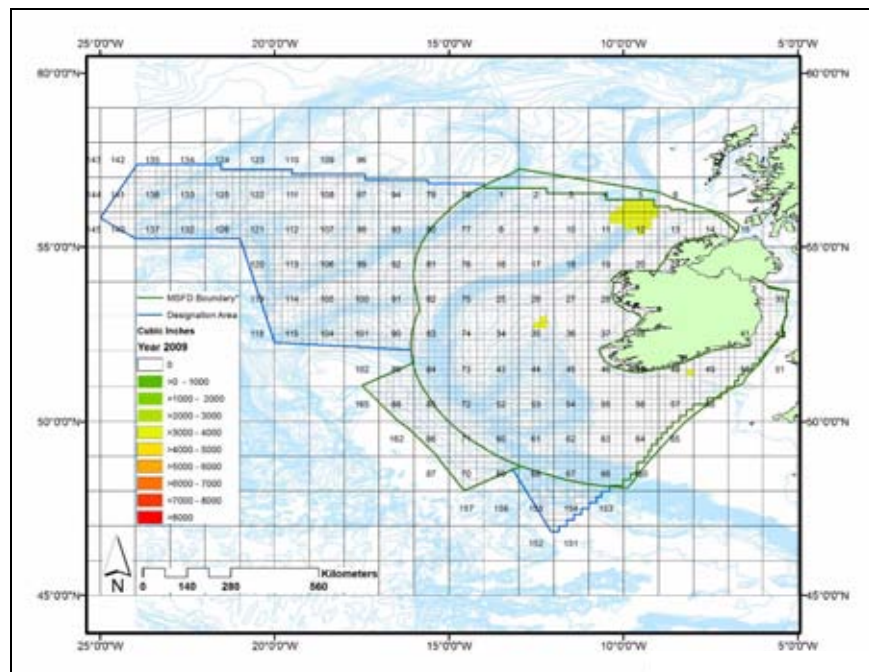


Figure 3.27. Seismic survey pressure in waters under Irish jurisdiction in the year 2009. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSDF) and is subject to change.

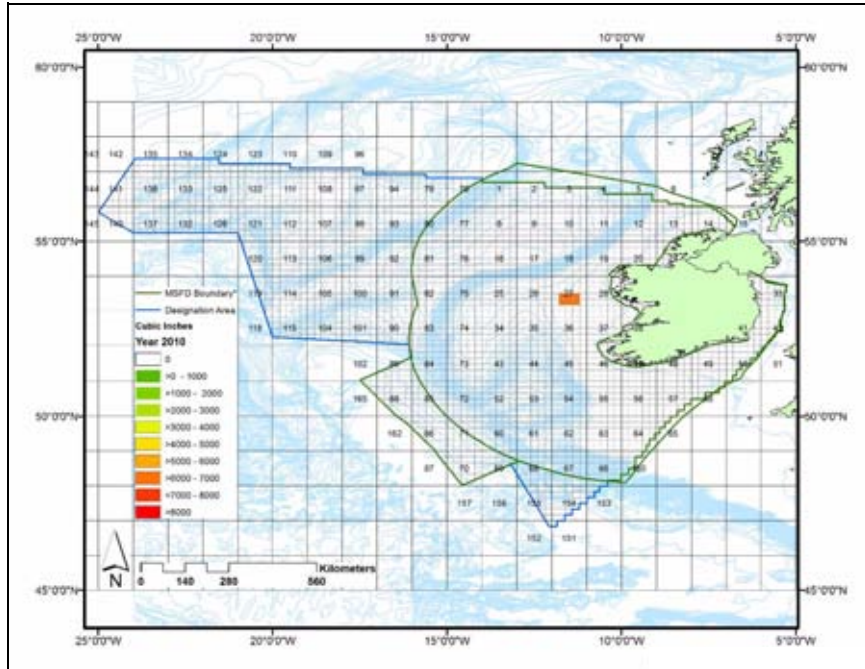


Figure 3.28. Seismic survey pressure in waters under Irish jurisdiction in the year 2010. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

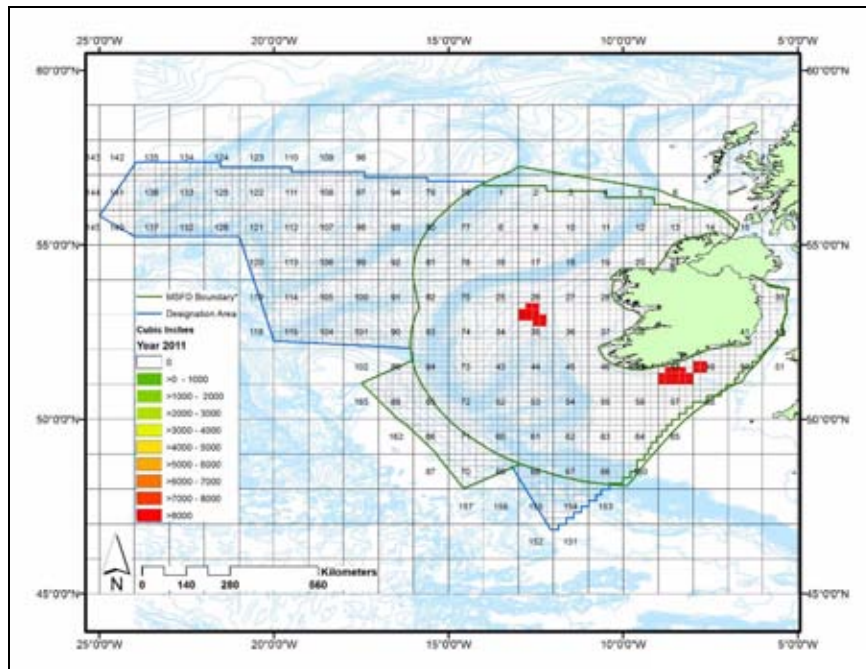


Figure 3.29. Seismic survey pressure in waters under Irish jurisdiction in the year 2011. Volume of air-gun arrays, in cubic inches, used for each survey is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive (MSFD) and is subject to change.

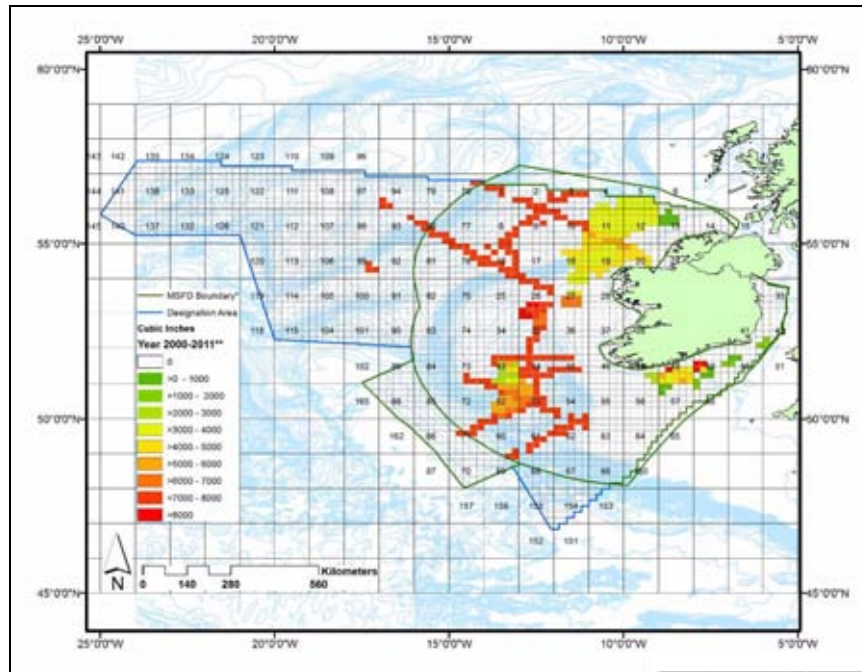


Figure 3.30. Seismic survey pressure in waters under Irish jurisdiction between 2000 and 2011. Mean volume of airgun arrays, in cubic inches, used in each cell block is represented by a graduated colour scheme, with the largest volume air-gun arrays shown in red. *MSFD Boundary is the currently proposed boundary under the Marine Strategy Framework Directive and is subject to change.

4 Discussion

The proposed method by the MSFD GES Technical Sub Group on Underwater Noise and other forms of energy (Van der Graaf et al., 2012) aims to assess specific geographical areas subject to seismic exploration. The method and results presented here develop these analyses further, aiming to highlight areas under seismic exploration but also to discern cumulative pressure on specific cell blocks between 2000 and 2011 in terms of total bang days and to develop an understanding of the varying intensities of air-gun array noise emissions across geographical regions. To the authors' knowledge, this is the first study to assess seismic exploration in waters under Irish jurisdiction from 2000 to 2011.

Interpretation of the analyses presented here gives a preliminary insight into the type of seismic exploration pressure that each cell block is subject to. It is apparent that 3D surveys, being more localised in nature, are accountable for a greater number of bang days per cell than 2D surveys. It is possible to broadly categorise pressure from seismic exploration in Irish waters for these two survey types. 2D surveys create infrequent bursts of impulsive noise, indicated by a low number of bang days but spanning a larger area, for example 0.17 bang days across 58 cell blocks for a 10-day survey using the results generated in this report, while 3D surveys produce frequent bursts of impulsive noise but within a localised area, for example 0.22 bang days across 15 cell blocks for a 10-day survey using the results generated in this report. Determining the effects of these two scenarios and which pressure is likely to yield the most detrimental affects to the marine environment, if either, is extremely difficult. Southall et al. (2007) reported the importance of multiple pulses in comparison with single pulses and recommended that cumulative sound exposure levels should be calculated in order to accurately determine if exposures exceed thresholds for Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS).

These results suggest a trend towards increasing authorisations for seismic surveys, indicating that oil

and gas exploration is on the rise in Irish waters. The Irish Offshore Strategic Environmental Assessments 3 and 4 produced by the PAD confirm this, estimating likely maximums of 49,000 km for 2D and 28,000 km² for 3D surveys between 2010 and 2016 in the Rockall Basin alone. The operation of 'open-door' licensing in the Irish and Celtic Seas estimated that a maximum of some 100,000 km for 2D and 30,000 km² for 3D will be surveyed between 2011 and 2020, by which point Ireland hopes to achieve GES under the MSFD.

It is suggestive from results presented here that the volume of air-gun arrays is increasing. Increasing the area authorised for seismic exploration, coupled with increased air-gun array volume, has the potential to lead to increases of anthropogenic noise in the marine environment. Richardson et al. (1986) reported avoidance reactions by bowhead whales with seismic pulses greater than 160 dB re 1 μ Pa but results were unclear as to their reactions to lower received levels. McCauley et al. (2000) observed humpback whales exposed to commercial seismic surveys with air-gun arrays of 2,678 cubic inches and to experimental surveys with air-gun arrays of 20 cubic inches. They reported avoidance by the whales at received levels of 160–170 dB re 1 μ Pa from both arrays, with avoidance from the commercial array at a distance three times larger than for the smaller volume experimental array. Differences in response to single airguns and full arrays have also been documented in seals (Harris et al., 2001), with a greater avoidance observed during full-scale array usage. These results indicate that the larger volume arrays used in Irish waters since 2007 maybe cause for greater concern. Studies conducted in British Columbia have focused on seismic air-gun noise propagation and concluded that received levels are dependent on seabed bathymetry and seasonal sound speed profiles in the water and the sub-bottom geoacoustic profiles (MacGillivray, 2007). Therefore, assessment of varying noise emissions from seismic air-gun arrays is not without difficulty.

The next step is to assess the effects of noise from seismic exploration on marine life. Assessment must

take into consideration the distribution of marine fauna in areas of highest pressure and determine the species of greatest concern both in terms of spatial and temporal overlap with seismic survey pressure but also in terms of vulnerability to increased noise emissions, current status of the population and life history parameters.

This report has highlighted specific geographical areas with the greatest frequency of seismic exploration, in terms of cumulative bang days per cell block and has also highlighted specific geographical areas subject to the larger volume arrays. However, it is clear from this study that the scale of surveys is highly variable and this needs to be taken into account. Further work should aim to combine these analyses and better understand the varying noise levels emitted from individual surveys. It may be beneficial to analyse waters under Irish jurisdiction by broad bathymetric

categories and also temporally, by season. It is imperative that some aspect of noise emissions for each survey is quantified to correctly assess Indicator 11.1.1 and to give an accurate representation of noise pressure from seismic surveying before deducing the extent to which marine fauna are affected.

Additionally, the use of 1 day as a temporal scale may not be the most ecologically relevant or accurate choice. A further development of this analysis may involve data reported at a finer scale such as acquisition time (hours), reporting noise in 'Bang Time'. This scale would reduce the underestimation of the bang days per cell; a survey is less likely to span more than one cell block per hour than per day. Data on acquisition time are readily available from the PAD and may be used in the future to determine which scale is best to assess the level of noise in Irish waters and its effect on marine fauna.

References

- André, M., Solé, M., Lenoir, M., Durfort, M., Quero, C., Mas, A., Lombarte, A., van der Schaar, M., Lopez-Bejar, M., Morell, M., Zaugg, S. and Houegnigan, L., 2011. Low frequency sounds induce acoustic trauma in cephalopods. *Frontiers in Ecology and the Environment* (<http://www.lab.upc.es/frontiers>).
- Blackwell, S.B., Nations, C.S.S., McDonald, T.L., Greene, Jr., C.R., Thode, A. and Macrander, A.M., 2008. Effects of sounds from seismic exploration on the calling behavior of bowhead whales. *Journal of the Acoustical Society of America* **124**(4:2): 2450.
- Castellote, M., Clark, C.W., Colmenares, F. and Esteban, J.A., 2009. Mediterranean fin whale migration movements altered by seismic exploration noise. *Journal of the Acoustical Society of America* **125**(4): 2519.
- Cato, D.H., Noad, M.J., Dunlop, R.A., McCauley, R.D., Salgado Kent, C.P., Gales, N.J., Kniest, H., Noadd, J. and Paton, D., 2011. Behavioural response of Australian humpback whales to seismic surveys. *Journal of the Acoustical Society of America* **129**(4): 2396.
- DFO, 2004. *Review of Scientific Information on Impacts of Seismic Sound on Fish, Invertebrates, Marine Turtles and Marine Mammals*. DFO Canadian Scientific Advisory Secretariat. Habitat Status Report, 2004/002.
- Doyle, T.K., 2007. Leatherback sea turtles (*Dermochelys coriacea*) in Irish waters. *Irish Wildlife Manuals*, No. 32. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.
- Engas, A., Lokkeborg, S., Ona, E. and Vold Soldal, A., 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). *Canadian Journal of Fisheries and Aquatic Science* **53**: 2238–2249.
- Finneran, J.J., Schlundt, C.E., Dear, R., Carder, D.A. and Ridgway, S.H., 2002. Temporary shift in the masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. *Journal of the Acoustical Society of America* **111**(6): 2929–2940.
- Gedamke, J., Gales, N. and Frydman, S., 2010. Assessing risk of baleen whale hearing loss from seismic surveys: the effect of uncertainty and individual variation. *Journal of the Acoustical Society of America* **129**(1): 496–506.
- Goold, J.C., 1996. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. *Journal of the Marine Biological Association of the United Kingdom* **76**: 811–820. doi:10.1017/S0025315400031477.
- Gordon, J., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M.P., Swift, R. and Thompson, D., 2003. A review of the effects of seismic surveys on marine mammals. *Marine Technology Science Journal* **37**(4): 16–34.
- Guerra, M., Thode, A.M., Blackwell, S.B. and Macrander, M.A., 2011. Quantifying seismic survey reverberation off the Alaskan north slope. *Journal of the Acoustical Society of America* **13**(5): 3046–3058.
- Harris, R.E., Miller, G.W. and Richardson, W.J., 2001. Seal responses to air gun sounds during summer seismic surveys in Alaskan Beaufort Sea. *Marine Mammal Science* **17**: 795–812.
- IWC (International Whaling Commission), 2005. *Chair's Report of the 56th Annual Meeting 19–22 July 2004*. Sorrento, Italy. International Whaling Commission, Cambridge, UK.
- MacGillivray, A., 2007. Summary of a recent study of seismic airgun survey noise propagation in Queen Charlotte Basin. *Canadian Society of Exploration Geophysicists Recorder*, Focus Article March 2007 pp. 28–29.
- Marine Institute, 2011. *The Stock Book*. Report to the Minister for Agriculture, Fisheries and Food. Annual Review of Fish Stocks in 2011 with Management Advice for 2012. Marine Institute, Galway, Ireland.
- McCauley, R.D., Jenner, M.N., Jenner, C. and Cato, D.H., 1998. Observations of the movements of humpback whales about an operating seismic survey vessel near Exmouth, Western Australia. *Journal of the Acoustical Society of America* **103**(5:2): 2909.
- McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M.N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J. and McCabe, K., 2000. Marine seismic surveys – a study of environmental implications. *APPEA Journal* **2000**: 692–708.
- NFS, 2012. *Draft Environmental Assessment of Marine Geophysical Surveys by the R/V Marcus G. Langseth for the Southern California Collaborative Offshore Geophysical Survey*. Report to the National Science Foundation Division of Ocean Sciences.
- NPWS (National Parks and Wildlife Service), 2007. *Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters*. National Parks and Wildlife Service, Dublin, Ireland.

- Nowacek, D.P., Thorne, L.H., Johnston, D.W. and Tyack, P.L., 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* **37**(2): 81–115.
- O'Brien, J., Berrow, S., McGrath, D. and Evans, P., 2009. Cetaceans in Irish waters: A review of recent research. *Biology and Environment: Proceedings of the Royal Irish Academy* **109b**(2): 63–88.
- OSPAR (OSPAR Commission), 2009. Overview of the impacts of anthropogenic underwater sound in the marine environment. OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, *Biodiversity and Ecosystems Series*, Publication No. 441/2009.
- PAD, 2008. *Third Strategic Environmental Assessment for Oil and Gas Activity in Ireland's Offshore Atlantic Waters: IOSEA3 Rockall Basin*. Report to the Department of Communications, Energy and Natural Resources.
- PAD, 2011. *Fourth Strategic Environmental Assessment for Oil and Gas Activity in Ireland's Offshore Waters: IOSEA4 Irish and Celtic Seas Environmental Report*. Report to the Department of Communications, Energy and Natural Resources.
- Pearson, W.H., Skalski, J.R. and Malme, C.I., 1992. Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Science* **49**: 1343–1356.
- R Development Core Team, 2011. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org/>.
- Richardson, J.W., Würsig, B. and Greene, C.R., Jr., 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. *Journal of the Acoustical Society of America* **79**(4): 1117–1128.
- Richardson, W.J., Greene C.R., Malme, C.I. and Thomson, D.H., 1995. *Marine Mammals and Noise*. Academic Press, San Diego, USA.
- Skalski, J.R., Pearson, W.H. and Malme, C.I., 1992. Effects of sound from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Science* **49**(7): 1357–1365.
- Slotte, A., Hansen, K., Dalen, J. and Ona, E., 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. *Fisheries Research* **67**: 143–150.
- Southall, B.L., et al., 2007. Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals* **33**(4): 411–522.
- Stone, C.J. and Tasker, M.L., 2006. The effects of seismic airguns on cetaceans in UK waters. *Journal of Cetacean Research and Management* **8**(3): 255–263.
- Tasker, M., Amundin, M., Andre, M., Hawkins, A., Lange, W., Merck, T., Scholik-Schlomer, A., Teilmann, J., Thomson, F., Werner, S. and Zakharia, M., 2010. *Underwater Noise and Other Forms of Energy*. Marine Strategy Framework Directive Task Group 11 Report.
- 'Van der Graaf, A.J., Ainslie, M.A., André, M., Brensing, K., Dalen, J., Dekeling, R.P.A., Robinson, S., Tasker, M.L., Thomsen, F. and Werner, S., 2012. *European Marine Strategy Framework Directive – Good Environmental Status (MSFD GES)*. Report of the Technical Subgroup on Underwater noise and other forms of energy. http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf
- Weilgart, L., 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* **85**: 1091–1116.

Acronyms

2D	Two-dimensional
3D	Three-dimensional
EEZ	Exclusive Economic Zone
GES	Good Environmental Status
MMO	Marine Mammal Observer
MSFD	Marine Strategy Framework Directive
NPWS	National Parks and Wildlife Service
PAD	Petroleum Affairs Division
PTS	Permanent Threshold Shift
TTS	Temporary Threshold Shift

Appendix 1

Table A1.1. Information provided by the Petroleum Affairs Division of the Department of Communications, Energy and Natural Resources for seismic surveys between 2000 and 2001. Data were gathered where available.

Information provided	Brief description
Survey ID	Unique ID of each survey given by year and order of occurrence, e.g. 2000_01
Company	Company controlling seismic survey
Acquisition Contractor	Company conducting data collection
Vessel	Vessel conducting data collection
Authorisation	Authorisation code, e.g. EL2/94
Prefix	e.g. PRV00-
Project Code	Unique code for a seismic project conducted by a company. The same code will apply for multiple surveys under one project, e.g. PR0067
PAM	Passive Acoustic Monitoring conducted during the survey – Yes/No
Area	Area of the currently designated continental shelf under exploration, e.g. Celtic Sea
Quads Covered	PAD quadrants covered by a survey, e.g. Q11
Cell Blocks Covered	PAD cell blocks covered by a survey, e.g. 11/2 (quadrant 11, cell block 2)
2D km Line	Total line in kilometres surveyed by a 2D survey
3D km² Area	Total area in kilometres squared surveyed by a 3D survey
Start Date	Date of the start of the survey
End Date	Date of the end of the survey
Acquisition Dates	Dates in which seismic data were acquired
Acquisition Time	Time (hours) in which seismic data were acquired
Source Type	Equipment used during survey for seismic exploration, including equipment specifications when available
Source Depth	Depth (m) of 'Source Type' during data acquisition
Streamer Length	Length (m) of streamer
Streamer Depth	Depth (m) of streamer
Group Interval	m
Processing Sequence	Sequence of data processing
Recording System	System used to record seismic data
Record Display Length	Time(s) of record display
Vertical Scale	cm/s
Lo Cut Filter	Hz & dB/Octave
Hi Cut Filter	Hz & dB/Octave
Sample Rate	m/s
Polarity	Increase in pressure is recorded as a negative number on tape

An Ghníomhaireacht um Chaomhnú Comhshaoil

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

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

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

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

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

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

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

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOIL

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

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

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

TAIGHDE AGUS FORBAIRT COMHSHAOIL

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

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

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

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

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

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

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

STRUCHTÚR NA GNÍOMHAIREACHTA

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

Tá obair na Ghníomhaireachta ar siúl trí ceithre Oifig:

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

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



ENVIRONMENTAL PROTECTION AGENCY
PO Box 3000, Johnstown Castle Estate, Co. Wexford, Ireland
t 053 916 0600 f 053 916 0699
LoCall 1890 33 55 99
e info@epa.ie w <http://www.epa.ie>



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