Chapter 9
Assessment of Impulsive and Continuous Low-Frequency Noise in Irish Waters

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Abstract As part of the European Union Marine Strategy Framework Directive (MSFD), member states are required to address noise pollution in the marine environment under Descriptor 11. This study aimed to provide a practical desk-based application of Descriptor 11 assessment, focusing on the main contributors of ocean noise pollution in Irish waters, seismic surveying and shipping. To highlight specific geographical areas subject to elevated levels of noise pollution, the proportion of days over a calendar year that seismic air guns were operational was calculated and the vessel density per 50-km^2 grids was determined across Ireland's exclusive economic zone (EEZ). Additionally, cetacean sighting data were used to determine the degree of spatial overlap between areas of elevated noise pollution and areas of cetacean abundance.

Keywords Marine Strategy Framework Directive • Impulsive • Continuous • Seismic • Shipping • Cetacean

1 Introduction

The underwater acoustic environment, once limited solely to inputs from geophysical and biological sound sources, now must adapt to increasing anthropogenic noise pollution. Seismic surveying is the primary technique used in the search for oil and

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natural gas reserves and is responsible for the emission of bursts of impulsive noise into the marine environment. Ireland was listed as one of the European Union (EU) countries with the highest energy dependence rates, 89% in 2011 (Eurostat 2013), resulting in an increased demand to discover indigenous natural gas and oil deposits. Seismic air guns generate predominantly low-frequency noise between 0 and 500 Hz and are one of the main sources of concern when assessing anthropogenic noise in Irish waters. Shipping has also long been recognized as the dominant source of underwater noise at frequencies below 300 Hz (Ross 1976; Hildebrand 2005), and increasingly, concerns have grown regarding continuous noise sources that propagate efficiently across ocean basins with the potential to cause further insidious impacts. In the north Pacific, low-frequency background noise has approximately doubled in each of the past four decades (Andrew et al. 2002), resulting in at least a 15- to 20-dB increase in ambient noise. Gerviase et al. (2012) also noted local rises in ambient-noise levels in the St. Lawrence Estuary, Canada.

The potential impacts of noise are not necessarily proportionate to the emitted noise levels. The assessment of the effects of noise must take into consideration the species of greatest concern, in terms of both spatial and temporal overlap but also in terms of vulnerability to increased noise emissions, conservation status of the population, and life history parameters. It is therefore important to utilize the existing knowledge on the distribution and ecology of sensitive marine species. There have been a number of recent reviews of the actual and potential impacts of sound sources on aquatic life (National Research Council 2003; Hastings and Popper 2005; Nowacek et al. 2007; Southall et al. 2007; Weilgart 2007; OSPAR 2009). Cetaceans have been continually highlighted as a high-risk group likely to suffer detrimental impacts from anthropogenic noise. This group has a highly developed auditory system and relies on sound as their primary sense for orientation, navigation, foraging, and communication (Au et al. 2000). The vocalizations and estimated hearing range of baleen whales overlap with the highest peaks of acoustic energy of air gun sounds and shipping and, consequently, these animals may be more affected by this type of disturbance than toothed whales (Southall et al. 2007). Twenty-four species of cetaceans have been recorded from Irish waters, six of which are baleen whales (O'Brien et al. 2009). *Balaenoptera physalus* (fin whale) is the most commonly observed large baleen whale in Irish waters. In 1991, Ireland declared its coastal waters a whale and dolphin sanctuary, but this was not supported by any additional legislative instruments. However, a number of national and international legislative agreements are in place for the protection of cetaceans, most notably the EU Habitats Directive. Additionally, translated into national law in 2010, the Marine Strategy Framework Directive (MSFD) aims to achieve good environmental status (GES) of European waters by 2020 and specifically addresses the impacts of noise in the marine environment. The ability to define and monitor GES under the MSFD remains a challenge, especially for Ireland, considering the scale of the Irish exclusive economic zone (EEZ) that occupies an area eight times that of the landmass. The primary objective of this study was to utilize the existing data to quantify the level of noise-emitting activities across specific geographic locations within Irish waters and determine the extent of spatial overlap with species of concern.

The mapping of these activities will allow the member states to outline areas of high noise pollution to aid in the decision as to where to locate long-term monitoring stations. Additionally, the data can be used in conjunction with direct measurements in the analysis of annual trends in ambient noise.

2 Methods

2.1 Analysis of Seismic Surveys

The MSFD Technical Subgroup on Underwater Noise made recommendations for the member states to create a noise register of licensed activities and through this establish the proportion of days within a calendar year over a specified area in which target sounds from seismic surveys occurred. To achieve this, the details of 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 (DCENR). 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, and this was deemed a suitable spatial scale for analysis of seismic activity under the MSFD Indicator 11.1.1. Noise emitted from the operation of air guns was considered the target sound, and "bang days" were then defined as days in which data from seismic surveying were acquired. Where acquisition dates were not available, seismic data acquisition was 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%). Noise maps were generated during the years 2000–2011 through ARCMap 10 geographic information system (GIS) software. If a survey spanned more than one cell block, then bang days were estimated as the total number of bang days divided by the total number of blocks for which the survey spanned. This is likely to be an underestimation of survey effort because most seismic surveys cover more than one cell block per day. Bang days across the entire study period were summed to create a noise map for 2000–2011 (Fig. 9.1). Surveys conducted from 2000 to 2011 in Irish waters were also categorized based on the volume of the air gun array in cubic inches and, where available, the peak-to-peak pressure in bar meters; where more than one survey covered a cell block, the mean volume/pressure was displayed.

2.2 Vessel Density

Details of vessel activity within Ireland's EEZ were acquired through automatic identification system (AIS) and vessel monitoring system (VMS) transponders. Data were obtained from the Irish Naval Service and the Department of Transport,

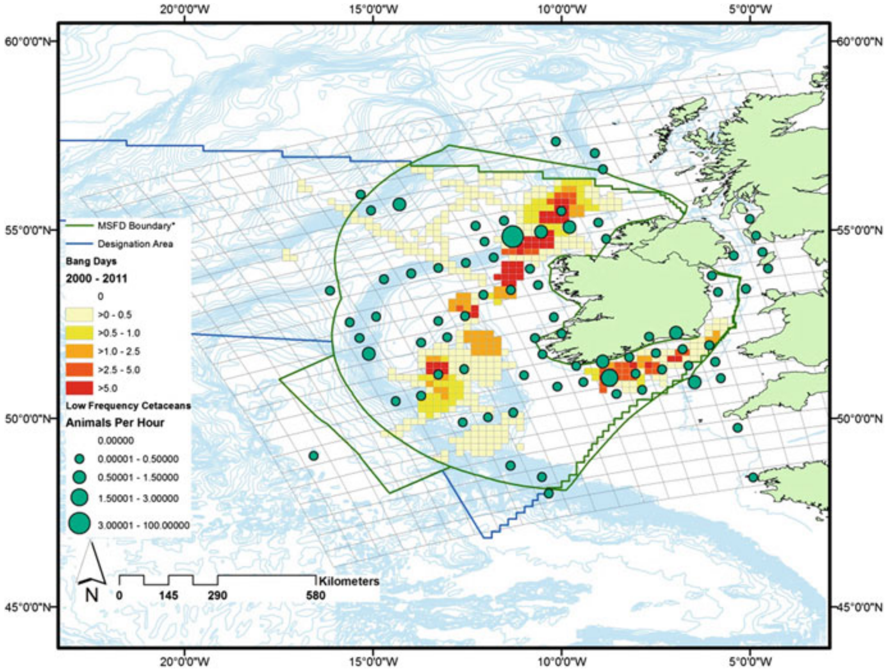

Fig. 9.1 Seismic survey pressure in waters under Irish jurisdiction between 2000 and 2011 with visual sightings of low-frequency cetaceans. Bang days, days involving acquisition of seismic data, are shown in a graduated color scheme, with darker colors representing the greatest number of bang days per cell. *MSFD* Marine Strategy Framework Directive

Tourism and Arts for Ireland. VMS data were obtained for 2010, 2011, and 2012, and AIS data were obtained for 2010 and 2011. VMStools, used under the R statistical software program, was used to format data-removing points on land, points recorded with implausible coordinates (i.e., latitudes >90° and longitudes >180°), points in harbors, and duplicates (records with the same coordinates and date-time stamps). Formatted data were then mapped using the ARCMap 10 GIS software as the total number of poll events across the European Environment Agency (EEA) 50-km^2 grid.

2.3 Cetacean Distribution

Visual cetacean sightings from 2005 to 2011 containing species identification, latitude, longitude, date, and time were obtained from the Irish Whale and Dolphin Group (Wall et al. 2013). Cetacean sightings were divided into the functional hearing groups previously categorized by Southall et al. (2007). Sightings databases were combined and formatted to remove any duplicate sightings and any sightings that could not be identified to a functional hearing group. Effort and sightings data were assigned to the EEA 50-km^2 grid using the ARCMap 10 GIS software. Total survey effort (hours surveyed in sea state 0–6) per 50 km^2 was summed and mapped for each grid square, as were the total number of individuals counted per 50 km^2 for each cetacean group recorded during the surveys. The relative abundance was calculated as the number of animals recorded per survey hour. Time-based analysis of the relative abundance was used because it was judged to be more suitable when amalgamating data from a variety of platforms with different speeds (Reid et al. 2003). The survey effort was graded based on sea state, with a sea state 2 or less for high-frequency cetaceans, sea state 4 or less for midfrequency cetaceans, and a sea state 6 or less for low-frequency cetaceans (Wall et al. 2013). Sea state grading is species specific, and so combining data into functional hearing groups has its limitations. The main concern is with the minke whale *Balaenoptera acutorostrata*, which is more elusive than the larger baleen whales and whose relative abundance will be understated when analyzed using sea states >3.

3 Results

3.1 Analysis of Seismic Surveys

Between the years 2000 and 2011, a total of 44 seismic surveys were conducted in waters under Irish jurisdiction. Of these, 25 surveys were two-dimensional (2-D) and 19 were three-dimensional (3-D). The duration of 2-D surveys during this time ranged from 1 to 51 days, with an average of 18 days. The duration of 3-D surveys ranged from 4 to 100 days, with an average of 31 days. For 2-D seismic exploration, an average of 5.77 cell blocks/day were surveyed. The more localized 3-D seismic surveys covered an average of 1.45 cell blocks/day. The most commonly used array volume in Irish waters between 2000 and 2011 was 3,000–4,000 in.^{3}. Trends in peak-to-peak (P-P) pressure were variable throughout the years; 2000 and 2008 reported the lowest values of 67 and 18 bar meters, respectively. The greatest P-P pressure was reported in 2011 with a value of 161.2 bar meters. Of the six surveys conducted in 2011, five of these used the same vessel and equipment setup.

3.2 Vessel Density

The AIS data-acquisition system was intermittently inactive for ~192 days in 2010 (53% of the year) and 241 days in 2011 (66% of the year) due to power failures and hardware malfunctions. The VMS data-acquisition system was fully functional throughout 2010, 2011, and 2012, and there were no reports of inactivity. Vessel density analyses in Ireland's EEZ have highlighted a number of areas that are

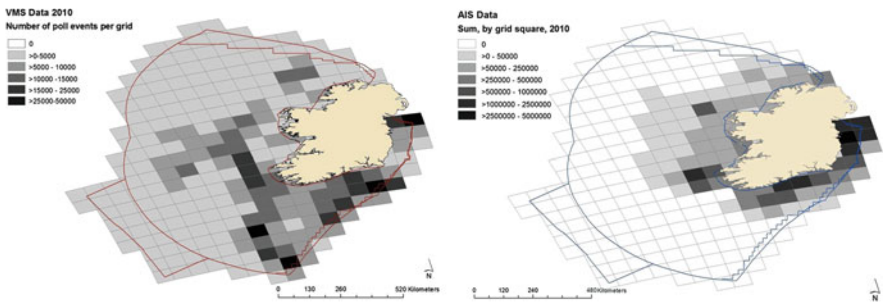

Fig. 9.2 Vessel density in 50-km^2 grids within Ireland's Exclusive Economic Zone from vessel monitoring system (VMS) data (*left*) and automatic identification system (AIS) data (*right*) for 2010

subject to higher densities of vessel traffic. AIS data analysis highlights the east and south coasts as high-density areas (Fig. 9.2); a proportion of this is likely to be attributed to passenger ferries operating routes between Ireland, the United Kingdom, and mainland Europe and commercial shipping on approaches to UK ports and the English Channel. VMS data analysis highlighted areas along the south coast of Ireland and areas further offshore south and southwest within Ireland's EEZ that were subject to high fishing vessel densities (Fig. 9.2). These areas were continually highlighted throughout 2010, 2011, and 2012.

3.3 Cetacean Distribution

The combined visual cetacean sightings database contained sightings from 2004 until 2011, with a total of 10,770 sightings. Of these, 2,466 sightings were identified as low-frequency cetaceans, 4,684 as midfrequency cetaceans, and 3,620 as high-frequency cetaceans. Results of cetacean distribution areas highlight a number of spatial overlaps with areas of noise-emitting activities in Irish waters. Quadrants 12, 18, 19, and 27 are of particular importance with high relative abundances of low-frequency cetaceans and high numbers of bang days for 2000–2011. Low-frequency cetaceans were also prevalent along the northwest continental shelf slope areas and slopes of the Porcupine Bank concurrent with high VMS densities. Low-frequency cetaceans also occurred along the south and southwest coasts of Ireland.

4 Discussion

The Irish Offshore Strategic Environmental Assessments (IOSEAs) 3 and 4, produced by PAD, estimate likely maximums of 49,000 km^2 for 2-D and 28,000 km^2 for 3-D surveys between 2010 and 2016 in the Rockall Basin alone (Petroleum

Affairs Division 2008, 2011). The operation of “open-door” licensing in the Irish and Celtic Seas estimated that a maximum of some 100,000 km^2 for 2-D and 30,000 km^2 for 3-D will be surveyed between 2011 and 2020, by which point Ireland hopes to achieve GES under the MSFD. This report has highlighted specific geographical areas with the greatest frequency of seismic exploration in terms of cumulative bang days per cell block. Noise emissions from 2-D surveys are spread across a wider area, leading to fewer bang days per survey block, for example, 0.17 bang days across 58 cell blocks for a 10-day survey, whereas noise emissions from 3-D surveys are usually focused on a smaller survey area, leading to a high number of bang days per survey block, for example, 0.22 bang days across 15 cell blocks for a 10-day survey. Studies have reported the importance of multiple pulses in comparison with single pulses (Southall et al. 2007). Additionally, previous work has documented responses that vary with air gun array volume. McCauley et al. (2000) reported avoidance by humpback whales at received levels of 160–170 dB re 1 μPa from a commercial array of 2,678 $in.^3$ and from an experimental array of 20 $in.^3$, with avoidance from the commercial array at a distance three times greater than for the smaller volume experimental array. Harris et al. (2001) also reported a greater avoidance in seals during full-scale array usage as opposed to a single gun. The results presented here aim to develop an understanding of the varying intensities of air gun arrays used across Ireland’s EEZ.

AIS and VMS data are useful resources for quantifying the densities of vessel traffic and allow member states to highlight “noisy” areas that may warrant further monitoring under the MSFD. Small recreational vessels and fishing vessels are also common in Irish waters but are not required to use AIS. The inclusion of VMS data aims to reduce this limitation. Vessel density analyses in Ireland’s EEZ have highlighted a number of areas that are subject to higher densities of vessel traffic. The east and south coasts highlighted as high-density areas under the AIS analysis can likely be attributed to passenger ferries operating routes between Ireland, the United Kingdom, and mainland Europe and commercial shipping approaches to UK ports and the English Channel. VMS data analysis highlighted areas along the south coast of Ireland and areas further offshore south and southwest within Ireland’s EEZ subject to high fishing vessel densities.

The cetacean distribution analysis highlights a number of spatial overlaps with areas of seismic surveying and vessel density in Irish waters. Of particular concern is the overlap with the low-frequency cetaceans because the auditory bandwidth of these species overlaps with the frequencies associated with shipping and seismic surveying. Quadrants 12, 18, 19, and 27 are of particular importance, with high relative abundances of low-frequency cetaceans and high numbers of bang days for 2000–2011. Low-frequency cetaceans were also prevalent along the northwest continental shelf slope areas and slopes of the Porcupine Bank concurrent with high VMS densities.

Low-frequency cetaceans also occurred along the south and southwest coasts of Ireland. The diet of fin and humpback whales in the Celtic Sea has been reported to be composed largely of *Clupea harengus* (herring) and *Sprattus sprattus* (sprat; Ryan et al. 2013). It is likely that the fishing vessels and the low-frequency cetaceans are utilizing the same natural resource in these areas of spatial overlap. Accurately predicting regions or periods where sensitive species are not present (or present in low densities) and authorizing surveying with this scientific knowledge in mind will help determine a spatial separation of surveys from periods of peak cetacean migration and foraging, minimizing exposure to anthropogenic noise and reducing the detrimental impacts of noise.

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