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Impulsive noise pollution in the Northeast Atlantic: Reported activity during 2015–2017

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ABSTRACT

Underwater noise pollution from impulsive sources (e.g. explosions, seismic airguns, percussive pile driving) can affect marine fauna through mortality, physical injury, auditory damage, physiological stress, acoustic masking, and behavioural responses. Given the potential for large-scale impact on marine ecosystems, some countries are now monitoring impulsive noise activity, coordinated internationally through Regional Seas Conventions. Here, we assess impulsive noise activity in the Northeast Atlantic reported during 2015–2017 to the first international impulsive noise register (INR), established in 2016 under the OSPAR Convention. Seismic airgun surveys were the dominant noise source (67%-83% of annual activity) and declined by 38% during 2015–2017. Reported pile driving activity increased 46%. Explosions and sonar/acoustic deterrent devices both had overall increases in reported activity. Some increases were attributable to more comprehensive reporting in later years. We discuss utilising the INR for risk assessment, target setting, and forward planning, and the implementation of similar systems in other regions.

1. Introduction

Impulsive sources of underwater noise pollution are among the most intense sounds in the ocean, and can cause a range of impacts on marine life, including mortality (Lewis, 1996; Danil and St. Leger, 2011; Popper et al., 2014), auditory damage (Lucke et al., 2009; National Marine Fisheries Service, 2018; Southall et al., 2019), displacement (Tougaard et al., 2009; Castellote et al., 2012; Thompson et al., 2013; Sarnocińska et al., 2020), acoustic masking (Blackwell et al., 2013; Kyhn et al., 2019), and physiological stress (Debusschere et al., 2016).

Sources of impulsive noise pollution include explosions (e.g. detonation of unexploded ordnance), seismic airguns (e.g. for offshore oil and gas exploration), and percussive pile driving (e.g. for offshore wind turbine installation). As impulsive noise propagates away from the source, the impulsive characteristics which carry heightened risk of auditory damage diminish (Hastie et al., 2019), but the remaining noise still has the potential to cause other effects and can travel great distances, with seismic airguns in the Atlantic Ocean being recorded up to 4000 km away (Nieukirk et al., 2012).

Activities which generate impulsive noise are widespread and persistent in many regions of the global ocean, leading to the risk of large-scale impact to marine ecosystems. Concern over such impacts has led

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policymakers to recognise the importance of managing underwater noise pollution (United Nations, 2018), and in some cases to enact legislation (e.g. European Commission, 2008) or develop policy (e.g. NOAA Ocean Noise Strategy) with the eventual aim of setting limits on cumulative noise levels.

A first step in implementing noise management at the international scale is to monitor and assess current levels of noise-generating activity. Since it is not feasible to comprehensively monitor impulsive noise levels in situ, this monitoring is instead carried out by gathering data on impulsive noise generating activities recorded as part of national regulatory licensing processes. In accordance with the EU Marine Strategy Framework Directive (MSFD), many EU Member States have now established national impulsive noise registers to monitor activity in their waters (Dekeling et al., 2014). Nevertheless, an internationally coordinated approach to monitoring, assessment and management is needed since impulsive noise pollution propagates across international boundaries and affects species and ecosystems which span large transnational areas.

To address the need for coordinated monitoring and assessment in the Northeast Atlantic, OSPAR (the Regional Seas Convention for the Northeast Atlantic) commissioned the International Council for the Exploration of the Sea (ICES) to develop and maintain the OSPAR impulsive noise register (INR; http://underwaternoise.ices.dk/) in 2015. The register is the first of its kind, and is now also used by HELCOM, the Regional Seas Convention for the Baltic Sea. The OSPAR INR is open access, and is used to assess the OSPAR Common Indicator of the Distribution of Reported Impulsive Sounds (OSPAR Commission, 2017). A similar register is now being developed for the Mediterranean Sea (Maglio et al., 2018).

Here, we provide details of the OSPAR INR and assess reported levels of activity in the Northeast Atlantic during 2015–2017. The first assessment of impulsive noise activity in the OSPAR Maritime Area was published in 2017 (OSPAR Commission, 2017) and covered only the first year of monitoring (2015). In this study, we examine three years of monitoring and assess interannual variability in the levels and distribution of activity, and evaluate progress toward comprehensive monitoring. We also discuss the application of the OSPAR INR to risk assessment, target setting, and forward planning to manage cumulative levels of impulsive noise pollution in the Northeast Atlantic.

2. Methods

Data were reported to the OSPAR INR by countries (Contracting Parties) cooperating under the OSPAR Convention. Each Contracting Party (CP) hosts a national noise register or monitoring programme, which records data on impulsive noise activities carried out in its waters and recorded as part of the regulatory consenting process (Fig. 1). These data are reported annually to the OSPAR INR using a standard format derived from a recommendation of the Marine Strategy Framework Directive (MSFD) Technical Group on Underwater Noise (Dekeling et al., 2014; OSPAR Commission, 2014). This format was developed in accordance with the OSPAR Common Indicator for impulsive noise, enabling standardised assessment of impulsive noise activity at the international scale. This international assessment can also provide broader context to assessments conducted at the national level

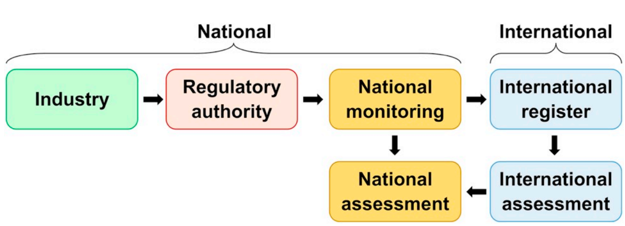

Fig. 1. Impulsive noise data reporting workflow. Data are currently reported annually to the international register from national monitoring programmes.

(Fig. 1). For example, the OSPAR Intermediate Assessment 2017 was used to inform and provide context to national assessments by Member States of the European Union under the MSFD in 2018.

Data are prepared in Extensible Markup Language (XML) format and uploaded to the register by CPs via an online interface. The spatial information reported to the OSPAR INR is provided either as point source information (i.e. the geospatial coordinates of the activity) or within a specified polygon area (e.g. UK oil and gas licensing blocks). The activities which qualify for inclusion in the OSPAR INR are impulsive sound sources having an energy source level > 186 dB re 1 μPa^2 m^2 s in the frequency range 10 Hz – 10 kHz, with more specific requirements for seismic airguns (zero-to-peak source level > 209 dB re 1 μPa m), explosions (equivalent TNT charge mass > 8 g), and sonar, acoustic deterrents, and other non-pulse sources (RMS source level > 176 dB re 1 μPa m; Dekeling et al., 2014; OSPAR Commission, 2014). Sound sources below these levels may occasionally be included if there is uncertainty over the source level of an activity. If noise abatement measures have been applied (e.g. bubble curtains for percussive pile driving), these must also be reported.

Further data on the intensity of noise sources can be reported to the register, via proxy parameters such as the maximum hammer energy of a pile-driving operation, the total airgun volume of a seismic survey, or the TNT equivalent of an explosion (OSPAR Commission, 2014). However, it was considered that there was insufficient confidence in the comparability of acoustic metrics derived from these proxy data across source types to warrant their inclusion in this study.

The spatiotemporal unit used in the assessment is termed Pulse Block Day (PBD): the number of days in which an anthropogenic impulsive sound source occurred within a specified spatial unit in a given calendar year. The spatial unit used in the OSPAR Maritime Area is the ICES statistical rectangle sub-division (ICES, 2019).

To compute the number of PBDs, it is necessary to convert the reported data into ICES rectangle sub-divisions. For point source data, the activity is assigned to the ICES rectangle sub-division in which it occurred. However, for polygon data the reported polygons do not generally align with ICES rectangle sub-divisions, and some CPs use polygons of different sizes for different activities. The convention adopted within OSPAR is to allocate activities to the ICES rectangle sub-division which contains the centroid of the reported polygon. In practice, the polygon data submitted so far to the OSPAR INR consist only of UK oil and gas blocks (the others being point source data or pre-formatted as ICES rectangle sub-divisions), which leads to a small overestimation of the spatial footprint of activities (e.g. 20% in 2015).

It is important to underline that the OSPAR INR only contains data which have been reported by CPs: not all CPs have made arrangements to report all qualifying activities in their waters, and some relevant activities may not currently require a licence (e.g. acoustic deterrent devices; Findlay et al., 2018; or small-scale inshore pile driving), meaning that data on these activities may not be recorded or reported.

3. Results

3.1. Data reported per country

The data reported to the OSPAR INR by each OSPAR CP during 2015–2017 are summarised in Table 1 by source type. Data were reported by 8 out of 12 relevant CPs. For each year and source type, each CP either (i) provided data on activity which had occurred; (ii) reported that no activity of that source type had occurred; or (iii) did not report. The general pattern is of more reporting in later years (Table 1).

3.2. Levels of activity by region

OSPAR divides its waters into five regions (Fig. 2), a convention which is retained here for convenience. Levels of reported activity (i.e.

Table 1
Inventory of data included in the study. X = activity reported. 0 = activity reported not to have occurred. Blank = not reported. 'Generic source' is used where the source type was not reported, and for some source types such as non-airgun seismic surveys which do not have a separate category (Dekeling et al., 2014; OSPAR Commission, 2014).

Contracting party	Year	Seismic airgun surveys	Pile driving	Explosions	Sonar and acoustic deterrents	Generic source
Belgium	2015			X		
	2016		X	X		
	2017		X	X		
Denmark	2015	X	X			
	2016	X	X			X
	2017	X	X		X	X
France	2015					
	2016	0		X		X
	2017	0		X		X
Germany	2015	0	X			
	2016	0	X			
	2017	0	X			
Ireland	2015					
	2016	X				
	2017	X				X
Netherlands	2015	0	X	X		
	2016	0	0	X		
	2017	X	0	X		
Sweden	2015			X		
	2016	X			X	
	2017					
UK	2015	X			X	X
	2016	X	X	X	X	X
	2017	X	X	X	X	X

reported PBDs) were highest in the North Sea, showing an overall decline of 66% from 4863 PBDs in 2015 to 1636 in 2017 (Fig. 2). This was due to the dominance of seismic airgun survey activity in this region (Fig. 3) which decreased over the assessment period.

Reported activity increased overall in the Arctic and Atlantic, Seas regions (Fig. 2). This increase was driven by seismic airgun activity (Fig. 3). In the Celtic Seas, there were increases in pile driving and sonar/acoustic deterrent device (ADD) activity (Fig. 3). The Biscay Region had relatively low levels of activity (Fig. 2) from explosions and non-airgun seismic sources (Fig. 3), which are reported under the generic sources category.

3.3. *Distribution of reported activity*

The distribution of reported activity changed markedly in each year of reporting (Fig. 4). A large-scale seismic airgun survey conducted in UK waters during 2015–2016 resulted in substantial areas of the northern North Sea, Northeast Atlantic, and Celtic Seas being exposed to impulsive noise sources (Fig. 5), typically for <5 days when expressed in pulse-block days at the resolution of ICES sub-rectangles (Fig. 4). In 2017, the area exposed was much smaller.

Some localised areas had a high proportion of calendar days with reported activity, with maxima of 76 PBDs recorded in the northern North Sea in 2015 (seismic airgun activity), 59 PBDs in the southern North Sea in 2016 (pile driving), and 101 in the northern North Sea region in 2017 (seismic airguns).

Reported seismic airgun activity was mostly in the northern North Sea and Atlantic (Figs. 3, 5), while reported impact pile driving occurred in the southern North Sea and coastal UK (Fig. 5). Reported sonar/ADD activity was concentrated in the Western English Channel and Southern Celtic Seas, with limited activity reported in the North Sea and Atlantic (Fig. 5). Most reported explosions occurred in the southern North Sea and Bay of Biscay (Fig. 5).

3.4. *Overall levels of activity by source type*

Seismic airguns were the dominant reported noise source in all three years (Fig. 6), and showed an overall decline of 38% between 2015 and 2017. There were overall increases in reported pile driving (46%), explosions (38%), and sonar/ADD sources (68%; Fig. 6), with an 18% increase in generic source activity (Fig. 6).

4. Discussion

4.1. *The international impulsive noise register*

The OSPAR INR is the first international monitoring tool to enable the assessment of impulsive noise pollution at the international level. In the first three years of reporting, both the spatial coverage and the number of source types reported have improved (Table 1), and the reporting process is now firmly established in a majority of countries

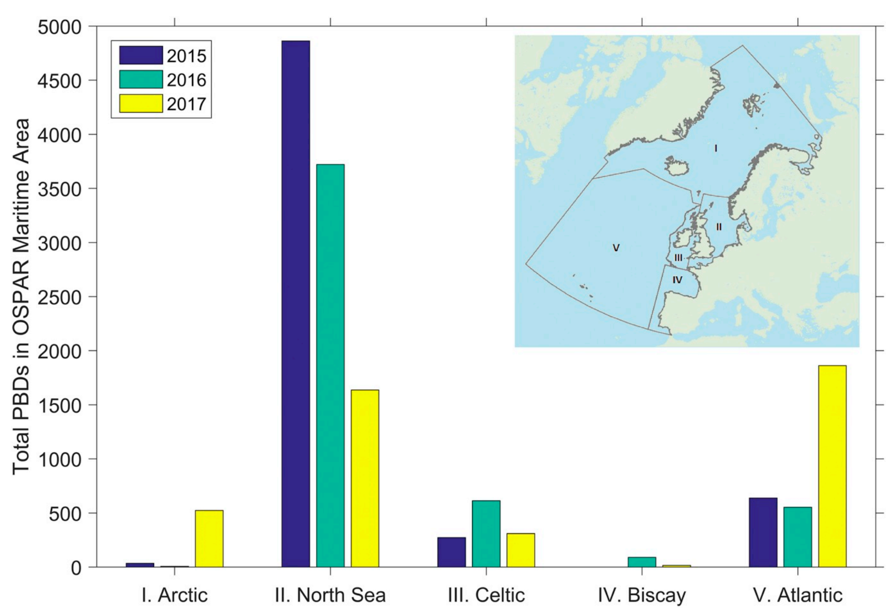

Fig. 2. Overall PBDs reported for each OSPAR Region. Inset: map of OSPAR Regions.

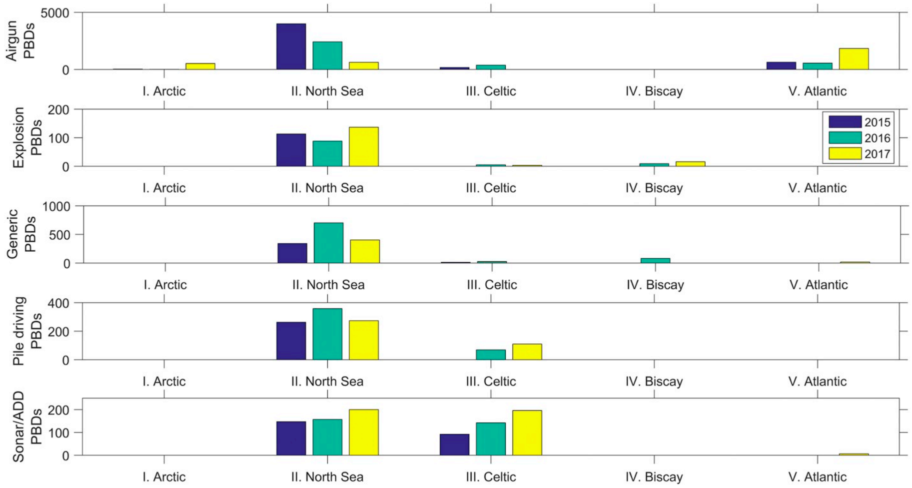

Fig. 3. PBDs for each OSPAR Region subdivided by source type. Note the differing scales on the y-axes.

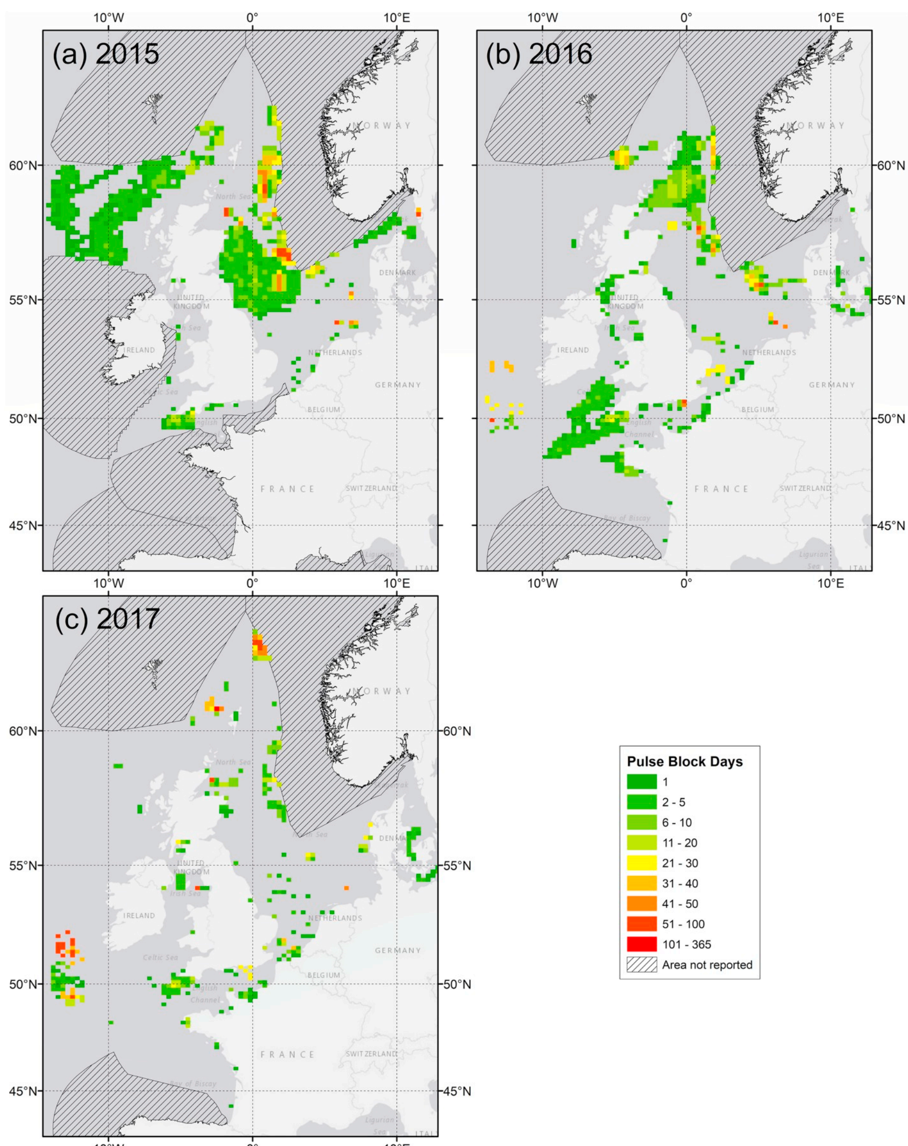

Fig. 4. Overall PBDs reported for (a) 2015 (b) 2016 (c) 2017.

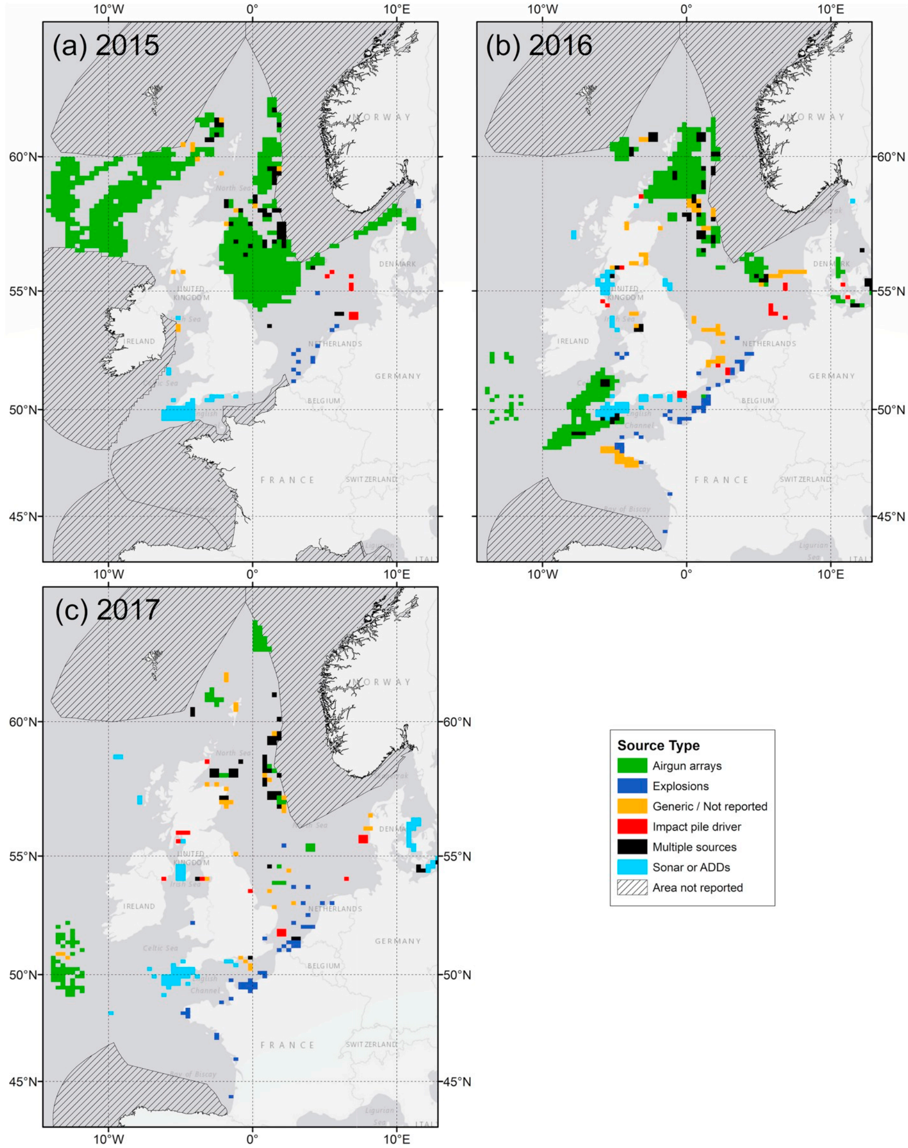

Fig. 5. Reported activity categorised by source type for (a) 2015 (b) 2016 (c) 2017.

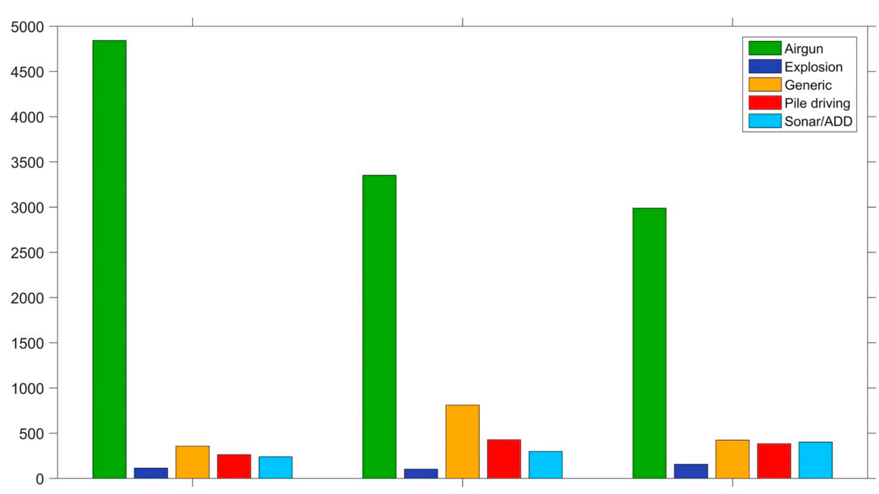

Fig. 6. Overall PBDs by source type for the entire OSPAR Maritime Area during 2015–2017.

within the OSPAR Convention. Increases in reported activity may therefore be attributable to actual increases in activity, or to improved reporting in the assessment period.

4.2. Significance of the results

Seismic airguns were by far the dominant source of noise reported (Fig. 6), and the overall decline in reported seismic airgun activity is likely due to the occurrence of an exceptional strategic survey conducted in UK waters in 2015–2016 by the UK Oil & Gas Authority (OGA, 2019), which covered large contiguous areas of UK waters. The decline in activity may also be due to the low oil price during this period. Seismic airgun surveys are largely conducted for the oil and gas industry, and while the data (Fig. 6) show a downward trend of 38% over 2015 to 2017, it is not clear that this trend will continue, since future seismic surveys are dependent on exploration activity levels. These results highlight that if efforts to meet carbon emissions targets reduce the extraction of fossil fuels, this could have the added benefit of reducing a major source of impulsive noise pollution in the Northeast Atlantic. Measures which could otherwise reduce noise from seismic airgun surveys include the use of quieter survey technologies (Merchant, 2019) and legal mechanisms to regulate noise emissions from this industry at the international level (Nowacek et al., 2015).

Reported pile driving activity increased overall during the assessment period, peaking in 2016 (Fig. 6). Some of this activity was due to inshore developments (e.g. port extensions), with the remainder attributable to offshore windfarm construction, particularly in the southern North Sea (Fig. 5). With the ongoing expansion of offshore windfarm construction in Europe to meet renewable energy targets (European Commission, 2009), it is anticipated that offshore pile-driving activity will continue to increase (BNEF, 2017). To reduce the risk of impact from this activity, some countries have already implemented regulations which effectively require noise abatement technologies such as bubble curtains to be applied at source (e.g. BSH, 2011), while others have yet to do so (Merchant, 2019). These regulations have encouraged industry to develop new abatement technologies and alternatives to piled foundations, such as suction buckets, drilled piles and floating turbines (OSPAR Commission, 2016).

Underwater explosions are some of the most intense and potentially damaging sources of manmade noise in the ocean, and can cause direct mortality and hearing damage to marine mammals and other marine taxa (Ketten et al., 1993; Lewis, 1996; Danil and St. Leger, 2011). Reported explosions were concentrated in the southern North Sea (Fig. 5), where the frequent discovery of unexploded ordnance (UXO), mostly World War II munitions, requires its disposal (typically by detonation) for safety reasons (von Benda-Beckmann et al., 2015). Acoustic modelling of this activity predicted that up to 5450 harbour porpoise may have incurred permanent hearing impairment in Dutch waters during a one-year period (2010 – 2011) in which 88 explosions were reported (von Benda-Beckmann et al., 2015). In the OSPAR area, reported explosions increased from 113 in 2015 to 156 in 2017 (38%; Fig. 6). To reduce the risk of impact from this activity, abatement measures such as bubble curtains or alternative disposal techniques to detonation, such as deflagration (non-explosive combustion), could be applied.

Although military activities are exempted from the obligation to report to the register, some navies voluntarily report unclassified sonar activity (conducted for training and testing purposes). Most reported sonar/ADD activity occurred off southwest England and in the Celtic Seas (Figs. 3, 5) and consisted of military sonar activity reported by the Royal Navy (UK). ADDs are also included in this category, since they are also active sonar devices known to affect marine life. ADDs may be deployed with the intention to deter seals from fish farms (Findlay et al., 2018), or to displace marine mammals from areas where more intense noise is going to occur (Wright and Cosentino, 2015), e.g. prior to pile-driving activity (Dähne et al., 2017; Graham et al., 2019).

4.3. Caveats

The reported data are not comprehensive, and further improvements to spatial coverage and the completeness of source types reported could be made. Significant omissions currently include Iceland, Norway, Portugal, and Spain. There are also some known data gaps in jurisdictions which are reporting. These include seismic airgun surveys (especially Norway and Greenland), navy sonar, inshore pile driving (e.g. ports and harbours), acoustic deterrent devices (particularly around fish farms; Findlay et al., 2018), and sub-bottom profiling. In general, challenges to reporting are presented by activities which do not require a licence, but do qualify for inclusion in the register. An area of particular interest is the Arctic, which currently has low levels of human activity but is expected to incur increased resource exploitation (including for oil and gas) as ice cover diminishes (Harsem et al., 2011; PAME, 2019). Achieving more complete reporting will require countries to establish reporting procedures for all relevant noise sources in their waters, ideally through established consenting procedures.

These results detail where and when impulsive noise activity is reported to have occurred. As such, they are an assessment of reported activity levels, and not an assessment of the pressure on marine ecosystems from impulsive noise, nor the potential impact of such pressure on marine ecosystems. However, it is envisaged that the register data will be used as the basis for assessing the risk of impact in future, and methods are being developed to do so (e.g. Drira et al., 2018; Merchant et al., 2018).

The intensity of noise sources was not considered in this study due to a lack of confidence in the completeness and consistency of these data. It is also debatable whether acoustic metrics offer a suitable proxy for the risk of impact, particularly in relation to behavioural responses (Handegard et al., 2013; Gomez et al., 2016; Dunlop et al., 2017). Further work is needed to derive suitable proxies for source intensity which are comparable across source types and relevant to the risk of impact. This should allow for the reduction in source intensity when using noise abatement technologies such as bubble curtains (OSPAR Commission, 2016). The thresholds for the inclusion of noise sources in reporting to the OSPAR INR are presently defined using sound pressure level (Dekeling et al., 2014; OSPAR Commission, 2014). However, fish and invertebrates are primarily sensitive to another component of sound known as particle motion (Nedelec et al., 2016; Weilgart, 2018), and this may need to be considered in assessing source intensity.

4.4. Outlook

The establishment of international noise registries is a first step in assessing and managing levels of impulsive noise pollution at the scale of regional seas (Dekeling et al., 2014). By considering the pressure that reported noise sources exert on different components of the marine ecosystem, the data recorded in the register can be combined with habitat and/or density data for relevant marine species to determine the extent of noise exposure (Maglio et al., 2015; Drira et al., 2018; Merchant et al., 2018) and to derive indicators of the associated risk of impact (Merchant et al., 2018). The quality of such assessments is contingent on the completeness of the reported data. Such methodologies can then be used as the basis for target setting and applied in marine spatial planning at national (Hatch et al., 2016; Faulkner et al., 2018) and international (Merchant et al., 2018) levels, thereby ensuring that cumulative levels of impulsive noise pollution are responsibly managed, as required by, inter alia, the EU MSFD and the OSPAR Convention. Ultimately, the use of noise registries for forward planning could lead to ‘noise budgets’ (Merchant et al., 2018) within regional seas which, if exceeded, would necessitate measures to limit noise emissions at sensitive times and locations, and/or the application of noise abatement measures (Merchant, 2019; Verfuss et al., 2019) to reduce noise emissions at source.

Since the establishment of the OSPAR INR, the HELCOM

Convention has adopted the same register, and other regions (e.g. Mediterranean; Drira et al., 2018; Maglio et al., 2018) and nations (e.g. USA; Hatch et al., 2016) are planning to implement similar registers.

CRediT authorship contribution statement

Nathan D. Merchant: Conceptualization, Formal analysis, Writing - original draft, Data curation, Writing - review & editing. **Mathias H. Andersson:** Data curation, Writing - review & editing. **Tetrienne Box:** Data curation, Writing - review & editing. **Florent Le Courtois:** Data curation, Writing - review & editing. **Dónal Cronin:** Data curation, Writing - review & editing. **Neil Holdsworth:** Data curation, Writing - review & editing. **Niels Kinneging:** Data curation, Writing - review & editing. **Sónia Mendes:** Data curation, Writing - review & editing. **Thomas Merck:** Data curation, Writing - review & editing. **John Mouat:** Writing - review & editing. **Alain M.J. Norro:** Data curation, Writing - review & editing. **Benjamin Ollivier:** Data curation, Writing - review & editing. **Carlos Pinto:** Data curation, Writing - review & editing. **Philip Stamp:** Writing - review & editing. **Jakob Tougaard:** Data curation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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