European Marine Strategy Framework Directive Good Environmental Status (MSFD-GES)

Report of the Technical Subgroup on Underwater Noise and other forms of energy

Final Report

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TSG Noise.

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Executive Summary

There are many kinds of anthropogenic energy that human activities introduce into the marine environment including sound, light and other electromagnetic fields, heat and radioactive energy. Among these, the most widespread and pervasive kind of anthropogenic energy is underwater sound. It is likely that the levels of sound inputs and the associated effects on the marine ecosystem have been increasing since the advent of steam-driven ships. Organisms that are exposed to sound can be adversely affected both on a short timescale (acute effect) and on a long timescale (permanent or chronic effects). These adverse effects can be widespread and the European Commission decided in September 2010 that the two indicators for underwater noise be used in describing Good Environmental Status.

The EC decided in 2010 that guidance was needed to help member states implement the indicators that were chosen in the Commission Decision of 2010 (EC 2010). TSG Noise therefore has focussed on clarifying the purpose, use and limitation of the indicators and described methodology that would be unambiguous, effective and practicable. For both the impulsive and ambient noise indicators it has been possible to make significant progress towards practical implementation of the indicators, and most ambiguities have been solved.

Impulsive Noise

Interpretation and aim: TSG Noise evaluated the terminology in the Commission Decision and concluded on a clarification in order to avoid misinterpretation. TSG Noise agreed that the impact that is addressed by this indicator is “considerable” displacement. This means displacement of a significant proportion of individuals for a relevant time period and spatial scale. The indicator is addressing the cumulative impact of sound generating activities and possible associated displacement, rather than that of individual projects.

GES and targets: At the moment it is difficult to provide a more specific description of GES beyond the text of the Directive, due to insufficient knowledge on the cumulative impacts of impulsive sound on the marine environment.

The initial purpose of this indicator will be to assess the pressure, i.e. an overview of all loud impulsive low and mid-frequency sound sources, through the year and through areas. This will enable MS to get an overview of the overall pressure from these sources, which has not been achieved previously. A necessary follow-up in future years would be to evaluate effects on biota and set targets and potentially take measures. Indicator 11.1.1 is a pressure-indicator, and a possible future target would thus be in the form of a threshold of, or a trend in, the proportion of days when impulsive sounds occur and in their spatial distribution.

Register: A first step is to establish the current level and trend in these impulsive sounds. This should be done by setting up a register of the occurrence of these impulsive sounds. TSG Noise recommends that MS work together to set up such a register, both at the regional level and the EU level. TSG Noise evaluated all aspects that need clarification and provided initial guidance on determining sources that need to be registered, spatial and temporal scale. TSG Noise considered whether quantitative relation between indicator and pressure (proportionality) could be improved

Ambient Noise

Interpretation and aim: Also for the Ambient Noise indicator TSG Noise evaluated the terminology in the commission Decision and concluded on a clarification in order to avoid misinterpretation.

During the meeting in February 2011, TSG Noise discussed what kind of averaging would best describe noise level. As a first approach TSG Noise suggests using the mean square

pressure. Unlike other types of averaging, it is expected to be robust to changes or differences in the duration of individual time samples.

Noise modelling should ideally be done together with in-situ measurements. The use of modelling will strengthen the analysis by overcoming bias introduced by changes in human activities or the by the natural variability of the environment and will extending the monitoring to poorly or un-covered areas.

GES and targets: At the moment it is impossible to define those elevations of ambient noise from anthropogenic sources that would cause the marine environment to not be at GES. This is mainly due to a lack of knowledge on the impacts of elevated ambient noise on the marine environment. The TSG cannot therefore advise on a level of ambient noise that could be set as a target for this indicator. However, since shipping is one of the largest contributors to low frequency ambient noise, the International Maritime Organisation (IMO) would need to be involved in potential future measures.

Monitoring: A first step towards monitoring is to establish the current level and any trend in ambient noise. This should be measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations. TSG Noise recommends that MS start a measurement programme as soon as possible in order to be able to define the current levels and trends in ambient noise (from shipping) by 2018

Methodological standards

There are no internationally accepted standards for terminology used to describe underwater sound. In 2010, in The Netherlands, Germany and the United Kingdom, collaborative projects were started to define and agree the terminology of underwater sound. The results of this cooperation are described in TNO (2011), and will likely be used as a basis for formal (ISO-) standards. Given the lack of a formal standard at present, TSG Noise recommends that Member States use the proposed standard terminology of TNO (2011).

Knowledge gaps

TSG Noise realises that there are a lot of unknowns around underwater energy and noise. TSG Noise has not attempted to identify all knowledge gaps around this issue, but focussed on that knowledge that is most urgently needed by MS in order to implement the indicators and further implementation of the MSFD, in particular the determination of Good Environmental Status and target setting.

The most relevant issues are:

- Better understanding of the impacts of noise on biota, in order to help MS to better specify GES. MS are required to review their marine strategies by 2018, six years after the initial establishment of the Directive.
- Research on the effects of energy sources that have yet to be addressed by MSFD indicators, for example high-frequency masking, effects of light, electromagnetic fields, etc. This would enable the appropriateness of indicators for these energy sources to be evaluated.

Other sources of energy and further research

High-frequency impulsive sounds and electromagnetic fields should be given priority for the development of indicators. For both energy sources further evidence as well as possible proposals for indicators could be considered in 2012/2013.

Road Map for work in 2012 and beyond

The TSG Noise has identified potential priority work items for support to the implementation of Descriptor 11 during 2012/2013. In 2012, the first priority of TSG Noise will be developing a practical guidance for MS for monitoring and noise registration that will enable assessment of the current level of the pressure.

Contents

1. Introduction

1.1 Background

In the Commission Decision 2010/477/EU on criteria and methodological standards on good environmental status (GES) of marine waters, two indicators were published for Descriptor 11 (Noise/Energy) of the Marine Strategy Framework Directive 2008/56/EC (MSFD). These are: Indicator 11.1.1 on 'low and mid frequency impulsive sounds' and Indicator 11.2.1 on 'Continuous low frequency sound (ambient noise)'. As a follow up to the Commission Decision, the Marine Directors in 2010 agreed to establish a Technical Sub-Group (TSG) under the Working Group on Good Environmental Status (WG GES) for further development of Descriptor 10 Marine Litter and Descriptor 11 Noise/Energy. For practical reasons DG ENV decided that the work would be carried out by two separate groups. This report compiles the recommendations of TSG Noise. Text box 1 shows the extract of the Commission Decision specifically for the indicators of Descriptor 11.

Text Box 1: Extract of the indicators for Descriptor 11 (Noise/Energy) from Commission Decision 2010/477/EU

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

Together with underwater noise, which is highlighted throughout Directive 2008/56/EC, other forms of energy input have the potential to impact on components of marine ecosystems, such as thermal energy, electromagnetic fields and light. Additional scientific and technical progress is still required to support the further development of criteria related to this descriptor, including in relation to impacts of introduction of energy on marine life, relevant noise and frequency levels (which may need to be adapted, where appropriate, subject to the requirement of regional cooperation). At the current stage, the main orientations for the measurement of underwater noise have been identified as a first priority in relation to assessment and monitoring, subject to further development, including in relation to mapping. Anthropogenic sounds may be of short duration (e.g. impulsive such as from seismic surveys and piling for wind farms and platforms, as well as explosions) or be long lasting (e.g. continuous such as dredging, shipping and energy installations) affecting organisms in different ways. Most commercial activities entailing high-level noise levels affecting relatively broad areas are executed under regulated conditions subject to a license. This creates the opportunity for coordinating coherent requirements for measuring such loud impulsive sounds.

11.1. 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 1μPa 2 .s) or as peak sound pressure level (in dB re 1μPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1)

11.2. Continuous low frequency sound

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

1.2 Purpose

The mandate for the Technical Subgroup on Noise (TSG Noise) was drafted by DG ENV, discussed by WG GES and issued by the European Marine Directors for the year 2011. For the full Terms of Reference of TSG Noise, see Annex 1. Members of TSG Noise are listed in Annex 2.

The work programme of TSG Noise contained the following items:

1) Identify and review existing data and monitoring methods on underwater noise;
2) Develop proposals for methodological standards for registering loud impulsive sounds;
3) Develop proposals to monitor low-frequency continuous sounds;
4) Assess the need to develop criteria and indicators for other forms of energy;
5) Provide a platform for sharing best practices on the development of what constitutes Good Environmental Status (characteristics of GES), environmental targets and associated indicators in relation to underwater noise;
6) Identify research needs and make recommendations for future work.

This report does not contain a concrete monitoring strategy for underwater noise, but rather contains background scientific information, and includes recommendations to the above work items.

1.3 How this report was developed

This report was developed by TSG Noise. The group was co-chaired by Mark Tasker (JNCC, UK) and René Dekeling (Ministry of Infrastructure and the Environment, the Netherlands) and supported by Sandra van der Graaf (RWS, the Netherlands).

The following events preceded the writing of this report:

- September 2010: Member States and stakeholders were invited to appoint experts to TSG Noise
- TSG Noise was convened twice: on 16 and 17 February 2011 at TNO in Delft (The Netherlands) and on 6 and 7 October 2011 at NPL in Teddington (UK)
- The final report was drafted in sections by members of TSG Noise (see below). These sections were compiled during December 2011 into a draft report. This report was reviewed twice by TSG Noise before finalisation.

This report was prepared in the following sections and by the named lead authors:

- Summary of experiences within Member States (Sandra van der Graaf)
- Review of existing knowledge on noise monitoring methods and other noise issues (Michel André)
- Glossary of indicator terminology (John Dalen and Michael Ainslie)
- Methodological standards for describing source levels of low- and mid-frequency impulsive sounds (Stephen Robinson, Michael Ainslie and John Dalen))
- A framework of options for Member State decisions on levels of anthropogenic sound sources that exceed levels that are likely to entail significant impact on marine animals (René Dekeling)
- Proposal for the establishment of a register of loud impulsive low- and mid- frequency sound sources (Mark Tasker)
- Interpretation of indicator 11.2.1 (Michael Ainslie and Frank Thomsen)
- Proposal for a monitoring scheme for low frequency continuous sounds (Frank Thomsen and Michel André)
- Technical specification of monitoring equipment (Stephen Robinson)

- Assessment of the need to develop criteria and indicators for other forms of energy (Karsten Brensing and Stefanie Werner)
- Considerations that may be taken into account when defining Good Environmental Status (Sandra van der Graaf)
- Recommendations for further research (Michel André)
- Interim reports and presentations for the WG GES (Mark Tasker, René Dekeling, Sandra van der Graaf)
- Final report (Mark Tasker, René Dekeling, Sandra van der Graaf, Jan Cools)

2. Underwater Noise

2.1 Types of underwater noise

There are many kinds of anthropogenic energy that human activities introduce into the marine environment including sound, light and other electromagnetic fields, heat and radioactive energy[1]. Among these, the most widespread and pervasive kind of anthropogenic energy is underwater sound. It is likely that these levels, and associated effects on the marine ecosystem have been increasing since the advent of steam-driven ships, although there have been very few studies that have quantified such a change. The numbers of anthropogenic electromagnetic fields are increasing due to the increasing number of power cables crossing our seas but these emissions are relatively local to the cables. Light and heat emissions are also relatively localised, but may have significant local effects (Tasker *et al*. 2010).

Energy input can occur at many scales in both space and time. Anthropogenic sounds may be of short duration (e.g. impulsive) or be long lasting (e.g. continuous); impulsive sounds may however be repeated at intervals (duty cycle) and such repetition may become “smeared” with distance and reverberation and become indistinguishable from continuous noise. Higher frequency sounds transmit less well in the marine environment whereas lower frequency sounds can travel far. In summary, there is great variability in transmission of sound in the marine environment.

Marine organisms that are exposed to noise can be adversely affected both on a short timescale (acute effect) and on a long timescale (permanent or chronic effects). Adverse effects can be subtle (e.g. temporary reduction in hearing sensitivity, behavioural effects) or obvious (e.g. worst case, death). These adverse effects can be widespread (as opposed to local for other forms of energy) and, following the recommendations of Tasker *et al.* (2009), the European Commission decided in September 2010 that the two indicators for underwater noise listed in Text Box 1 should be used in describing Good Environmental Status (Commission Decision 2010/477/EU on criteria and methodological standards on good environmental status (GES)). This report therefore focuses largely on these indicators of underwater sound and to a lesser extent on other sources of energy.

Text Box 2: Sound or Noise?

Sound or Noise?

For this report “noise” is taken to mean sound that has the potential to cause negative impacts on marine life

The term “sound” is used to refer to the acoustic energy radiated from a vibrating object, with no particular reference for its function or potential effect. “Sounds” include both meaningful signals and “noise” which may have either no particular impact or may have a range of adverse effects. The term “noise” is only used where adverse effects are specifically described, or when referring to specific technical distinctions such as “masking noise” and “ambient noise.”

(Based on Southall *et al.* 2009 and Tasker *et al.* 2009)

[1] Radio-active energy is considered as a contaminant and included in Descriptor 8 of the MSFD

2.2 Effects of underwater sound – background

Despite much research in recent years, the effects of underwater sound on marine organisms are still not well understood. Effects that are known are generated by a variety of types of sound and different organisms have differing sensitivities to sound (both pressure and particle motion). The result is that it is not possible to provide one measurement to describe the effect. A combination of different characteristics/measurements is thus required. An additional challenge is the lack of standardised protocols and associated terminology for measuring and describing underwater sound. Considering the many challenges that still exist for the characterisation of underwater sound, this section is an attempt to describe the characteristics that are indispensable for the characterisation of sound sources in the marine environment and give reasons to why these characteristics should not be bound to one unique value.

2.3 Characterising underwater sound

Sound in water is combination of travelling waves in which particles of the medium are alternately compressed and decompressed. The sound can be measured as a variation in pressure within the medium, which acts in all directions, and described as the sound pressure. The SI unit for pressure is Pascal (newton per square metre). A complementary measure of sound is in terms of the particle motion component, indicating the displacement (m), the velocity (m s^{-1}) and the acceleration (m s^{-2}) of the particles in the medium. Depending on the animal's receptor mechanisms, marine life is sensitive to either pressure or particle motion or both. Marine research over the past 30 years has demonstrated clear evidence that many fish and invertebrates respond to sound particle motion as well as sound pressure (Sand and Karlsen 2000, Ona *et al*. 2007, Sand *et al*. 2008, IMO-MEPC 2008, Sigray and Andersson 2011). The pressure can be measured with a pressure sensitive device such as a hydrophone (an underwater microphone). Due to the wide range of pressures and intensities as well as taking the physiology of marine life into account, it is customary to describe sound using a logarithmic scale. The most generally used logarithmic scale for describing sound is the decibel scale (dB) using one microPascal (1 µPa) as reference pressure (Bradley and Stern 2008).

The sound pressure level (SPL) is a measure of the effective pressure of a sound, averaged in time, and relative to a standard reference pressure. More specifically it is the root mean square (RMS) acoustic pressure expressed as a level, in decibels. The reference pressure in underwater acoustics is defined as 1 microPascal (symbol µPa), which is one millionth of a Pascal. The SPL values in water cannot be directly compared to those in water as a consequence of different reference pressures and the differences in impedance between water and air.

Other characteristics of acoustic pressure in use are **peak** pressure, **envelope peak, peak-to-peak and peak–RMS** measurements. RMS values have been used in some cases to establish a safe sound exposure level for marine mammals Yet, it is clear that RMS values as a sole characteristic is not sufficient in most cases e.g. for impulsive sounds (Madsen 2005). Recently proposed criteria for underwater animals by Hastings and Popper (2005) and Southall *et al*. (2007) are of dual nature, providing limits both for the peak sound pressure and for the sound exposure level.

Due to the (historical) absence of widely accepted definitions, method of measuring, processing and reporting for these terms, particularly for impulsive sound the use of reported SPL levels leads to confusion, and comparison between distinct measurements is often difficult or impossible because it not clear which characteristic is reported. Measurements e.g. of the level of a single impulse sound generated by impact pile driving can vary by more than 20 dB, depending on protocol and the chosen meaning.

Sound exposure level (SEL) takes the different duration of sounds into account and it is a measure of the accumulated energy over a defined period (often 1 second). It also allows the comparison of sounds of different durations. The SEL is the integral of the squared acoustic pressure with respect to time, expressed as a level in decibels over defined period.

Power spectral density level: All organisms can only perceive a limited subset of sound frequencies, depending on their perception mechanisms. It is therefore necessary to describe how the power of sound relates to the frequency. Power spectral density level is expressed in dB re 1 $\mu Pa^2/Hz$ and represents the average sound pressure for each band of width 1 Hz.

Octave band level: When considering the impact on marine organisms, broader frequency bands are often chosen, with **1/3 octave bands** most commonly used (See Glossary in Annex 3 for a definition of third-octave bands).

2.4 Measuring underwater sound

Underwater sound levels can either be measured or modelled. Underwater sound measurements are indispensable for the purpose of validating models. Measurements can be taken using fixed hydrophones or moving hydrophones, e.g. by attaching them to a towed cable or to marine animals. Fixed location measurements can be compared against criteria for environmental sound. Modelling can be used to estimate sound levels at locations where measured values are not available. Products of modelling include sound maps and exposure profiles of organisms. These methods are elaborated in de Jong *et al*. (2010).

Sensors can be either sensitive to pressure changes or to particle motion. A pressure hydrophone transforms the acoustic pressure into an electrical output. Hydrophones usually consist of crystals or ceramic elements that induce a small electrical voltage when being deformed by local pressure changes (piezoelectric effect).

The aim of sound measuring equipment is to obtain a proper digital representation of the acoustic pressure, i.e., the required bandwidth and dynamic range should be adequate and the equipment itself should not add too much unwanted sound (self-noise). Further, it should not unnecessarily affect the signal with its sensor characteristics. To avoid influencing the signal the measurement chain - acoustic sensor(s), amplifier(s), filter(s), analogue-to-digital converter(s), and in some cases also some pre- and post-processing - should be carefully designed. Batteries are a safe choice due to other power supplies being often noisy. In the following section, the measurement chain is discussed in more detail. Section 4.4 elaborates more on the measuring of underwater sound.

Data can be processed in real-time (i.e. while measuring) or off-line. Off-line processing first stores and in a second step processes measured data. Real-time processing requires less space since the raw unprocessed data are not stored but has the risk that potentially useful information is discarded. The main advantage of real-time processing is that analysed data are directly available. Off-line processing has the potential to be implemented continuously and over long time periods, resulting in large and representative datasets. Well-focused measurements on the needed frequency bands can reduce the required disk space and consequent challenges in transferring and analysing the database (André *et al*. 2011). The type of data processing depends on the objectives of the monitoring. Similar to measuring water quality, regular long-term measurements are needed at defined locations.

The sound source level is not a directly measurable quantity, but must be derived from measurements of received sound at some distance away from the source, A review of underwater sound sources (Ainslie *et al*. 2009) revealed that useful information of source characteristics is very scarce, due to the lack of standardization and clarity on the definition of the sound source level. In air, a variety of source-specific assessment standards and noise control legislation are in place for motor vehicles, aeroplanes, outdoor equipment and household appliances.

2.4.1 Sound mapping

One of the applications mentioned in EU Directive 2002/49/EC on environmental noise in air is generating *strategic noise maps*, which are useful for spatial planning in relation to sound exposure. Similar sound maps for underwater sound are proposed in Ainslie *et al*. (2009). A sound map may show a representation (often two-dimensional) of sound distribution in five dimensions: the three spatial dimensions as well as time and frequency. Here the differences between the air and underwater domains become clear. In air, the frequency content of the sound is partly ‘removed’ via the concept of an A-weighted sound level, which represents the sound as observed by human hearing. In the underwater domain, with its wide variety of marine species, which all have different hearing sensitivities; a similar approach would require separate maps for each (group of) species. Another difference is the fixed height that is representative for sound reception by human observers in air, whereas different species use different parts of the water column. In the development of two-dimensional sound maps for the three-dimensional underwater environment a choice has to be made whether to present noise indicators for a given depth or for a (weighted) average over depth. The sound field can be strongly depth dependent, especially at low frequency and close to the sea surface and bottom. The third choice is for the temporal component of the noise indicator. Instead of long-term averaged noise indicators, it may be useful in some cases to present maps of the sound exposure due to a single event (e.g. an explosion) or a limited period of activities (e.g. piling of a single monopile). The long term may also be split into seasonal variations, day-night differences, etc. It means that different sound maps may present different noise indicators, dependent on the application.

It is not possible to produce maps from measurements only, because it is not practicable to measure sound at all map locations in an appropriate time frame. Hence, sound mapping requires the use of models for the sound distribution. These models need data that describe the sources of sound, which can be directly measured or based on earlier measurements. The sound propagation models are dependent on many environmental parameters (e.g. temperature through the water column and sediment properties) that in general are only known with a limited accuracy. This means that additional measurements are required to validate the model predictions.

2.5 Methodological standards

There are no internationally accepted standards for terminology used to describe underwater sound.

Two committees of the International Organization for Standardization (ISO) are currently working on standards that are relevant for the MSFD, namely the new sub-committee on standards for underwater acoustics (ISO TC43, sub-committee 3 (SC3)) and technical committee on Shipping and Maritime Technology (ISO TC8).

The scope of SC3 of ISO TC43 is “Standardization in the field of underwater acoustics (including natural, biological, and anthropogenic sound), including methods of measurement and assessment of the generation, propagation and reception of underwater sound and its reflection and scattering in the underwater environment including the seabed, sea surface and biological organisms, and also including all aspects of the effects of underwater sound on the underwater environment, humans and aquatic life.” ISO TC43 SC3 WG1 has adopted ANSI S12.64 (ship noise measurement for deep water) as a basis for a Draft Publically Available Specification (DPAS), which will become ISO17028:2011.

TC8 is also working on a standard for ship noise measurement within ISO TC8 SC2 WG6. This work might be combined with the work of TC43. The draft standard from TC8 is ISO DIS 16554 “Ships and marine technology - Protecting marine ecosystem from underwater radiated noise - Measurement and reporting of underwater sound radiated from merchant ships”.

In 2010, in The Netherlands, Germany and the United Kingdom, collaborative projects were started to define and agree the terminology of underwater sound. The results of this cooperation are described in TNO (2011), and will likely be used as a basis for formal (ISO-) standards. Given the lack of a formal standard at present, TSG Noise recommends that Member States use the proposed standard terminology of TNO (2011). The proposed terminology is followed throughout this report. A brief overview of characteristics used to describe underwater sound is provided below. A small number of terms that are specific to the two Indicators 11.1.1 and 11.2.1 are defined in the Glossary (Annex 3).

2.6 Experience of Member States in developing the GES indicators of underwater sound

As a first assessment of the progress by European Union Member States in developing indicators, national information was gathered from EU-member states that are also Contracting Parties (CP) to OSPAR. A questionnaire was sent out to OSPAR Contracting Parties in December 2010. The questionnaire was returned by 9 CPs (BE, DE, DK, FR, IE, NL, SE, ES, UK). Additional information was sought from EU Member States not party to OSPAR through both WG-GES and the EU Marine Directors group, however, no further information was received. The OSPAR report and the advice document based on this report are available on request from the OSPAR secretariat (www.ospar.org)

It was clear from the responses to the questionnaire that different Contracting Parties were at differing stages of implementing and interpreting this descriptor and that there was large variation in actions between Contracting Parties. There was a general agreement that a definition of GES and the setting of targets were not possible before the work of TSG Noise was completed. It was acknowledged that target setting for this descriptor would be difficult for several reasons:

- There are no baselines and it is thus not possible to quantify the indicators
- Knowledge and understanding of the effects on the marine environment is limited, however progress is being made, e.g. thresholds have been established for various forms of damage caused by noise to marine mammals and fish (for an overview of these see OSPAR 2009). Those thresholds may be used to express risk arising from noise. There is a need for more research to obtain scientifically-founded thresholds for sounds that adversely affect marine organisms.

To date, monitoring of underwater sound by OSPAR Contracting Parties has been mainly undertaken at a project level. No Contracting Party has incorporated underwater sound into any permanent monitoring programme. At a project specific level, underwater sound has been recorded in some locations in relation to:

- construction and operation of offshore wind farms
- seismic surveys and drilling projects of the offshore oil and gas industry
- construction of harbours, bridges and tunnels
- military activities
- dredging (sand/gravel dredges and dredging for navigational purposes)

Research programmes have started in almost all Contracting Parties, addressing one or more sources and types of underwater sound, as well as the effects of sound on the marine environment. An overview of research programmes in OSPAR Contracting Parties is provided in OSPAR (2009).

3. Low and mid frequency impulsive noise (Indicator 11.1.1)

3.1 Summary

High amplitude, low and mid-frequency impulsive anthropogenic sounds have caused most public concern, particularly in relation to perceived effects on marine mammals and fish. This type of sound can come from pile driving, seismic surveys and explosions. Laboratory studies have shown physiological and behavioural effects in a variety of marine organisms, while field studies have shown behavioural disturbance and in some cases death. There is a variety of degradation gradients caused by impulsive noise, the scale of these depending on the marine organism under consideration and the loudness, frequency and persistence of the sound. In principle, underwater sound is likely to have greater adverse effects at higher sound amplitudes (loudness) and with a greater number of inputs (persistence). Lower frequency sounds have the potential to affect a wider area than higher frequencies, but the actual impacts on any organism will depend on the frequency range to which it is sensitive; sounds outside their range of detection will be less likely to have an adverse effect (Tasker *et al*., 2010).

The choice of the upper limit of the frequency band (10 Hz to 10 kHz) in the Commission Decision 2010 is based on the fact that sounds at higher frequencies do not travel as far as sounds within this frequency band. Although higher frequency sounds may affect the marine environment, they do so over shorter distances. This choice of bandwidth, therefore, also excludes most depth-finding and fishery sonars. The indicator is focused on those impulsive sound sources that are most likely to have adverse effects, and the sources that generate sound in this frequency band. The source levels should include all classes of high intensity sounds that are known to affect the marine environment adversely; the activities that generate such sounds are routinely licensed or are assessed. Task Group 11, that advised on development of the underwater sound indicators, recommended that the source levels be reviewed in the future in the light of any new scientific publications (Tasker *et al*. 2010)

3.2 Interpretation of Indicator 11.1.1

The Commission Decision of September 2010 defines Criterion 11.1 and Indicator 11.1.1 as follows:

> **Criterion 11.1: Distribution in time and place of loud, low and mid frequency impulsive sounds**
>
> Indicator 11.1.1: Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1μPa2.s) or as peak sound pressure level (in dB re 1μPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1)

This description of this indicator is not unambiguous and there is a need for an explanation how it should be interpreted. The ambiguities were addressed and discussed in the meetings of the TSG Noise, in order to have an unambiguous description. TSG Noise interpreted Indicator 11.1.1 on low and mid-frequency impulsive sounds as follows:

The proportion of days and their distribution within a calendar year, over geographical locations whose shape and area are to be determined, and their spatial distribution in which either the monopole energy source level (in units of dB re 1 μPa² m² s), or the zero to peak monopole source level (in units of dB re 1 μPa² m²) of anthropogenic sound sources, measured over the frequency band 10 Hz to 10 kHz, exceeds a value that is likely to entail significant impact on marine animals (11.1.1).

The following points should also be kept in mind:

- The basic principle of the MSFD is that it addresses the ecosystem (consideration 5: the development and implementation of the thematic strategy should be aimed at the conservation of the marine ecosystems). This indicator is addressing the cumulative impact of activities, rather than that of individual projects. Effects of local/singular activities are therefore not covered by this indicator, and this indicator on its own is not intended, nor is it sufficient, to manage singular events. Environmental Impact Assessments (EIA) can be used to assess and in some cases limit the environmental impacts of individual projects. TSG Noise noted also requirements of other European legislation that may restrict use of underwater sound sources due to their effects on certain marine animals. Options for mitigation are also sometimes included as part of EIA and other licensing procedures.
- Measuring sound levels should not take place at one metre from the source, as the original text of Indicator 11.1.1 expresses. TSG Noise concluded that source level is meant here. Therefore, the sound level has to be referred (back-calculated) to one metre taking into account modelled propagation loss during measurement.
- The quantities monopole energy source level and zero to peak monopole source level do not include a frequency weighting to account for the sensitivity of marine species to different frequencies of sound.
- If the “proportion of days and their distribution within a calendar year” is interpreted as “proportion of days by season”, this Indicator could comprise four values per geographical location, one for each season of the year. Other subdivisions of the calendar year are also possible.

In the Commission Decision the indicator for impulsive sound is defined. The indicator addresses impulsive sounds that exceed levels that are likely to entail significant impact on marine animals. If this indicator is to be used in management, it is important to decide which impacts are the most relevant and to improve understanding of when (cumulative) effects exceed a “significant” level. This will enable clear choices in the practical use of the indicator.

An indicator on impulsive sounds should register all relevant impulsive sounds. Only after a registry has been created would it be possible to test the current status against a “good” status (GES) and consider whether the impact is significant. There is a risk that some sound sources fail to be included in the registry because they are not considered significant on their own, while the effects of these sources may impact cumulatively with other impulsive sounds. It is therefore important that all relevant impulsive sounds are registered

In the original proposal for this indicator from the TG 11 the term ‘significant’ was not used, instead sound levels were proposed. This would have avoided the risk described above. For practical reasons, it is proposed to interpret the phrase significant as “serious adverse impacts”. This is also the translation in some languages of the phrase ‘significant’ in the Commission decision, and this interpretation is supported by the description of Descriptor 11 in the text of the MSFD.

The indicator does not need to cover all possible impacts of impulsive noise. The indicator must be useful in establishing whether Good Environmental Status is achieved and must be practicable for management and target setting. Therefore, the indicator may address only a single impact of impulsive noise, especially if this is the most relevant impact or if description of one impact implicitly covers other impacts.

Text Box 3: What is "impulsive sound"?

What is "impulsive sound"?

Introduction

TSG Noise discussed the meaning of the term "impulsive sound" in the context of Descriptor 11, and concluded it to imply a sound comprising one or more pulses, each of short duration, and with long gaps of no significant sound emission between these pulses. Of particular concern to TSG Noise, because of their potential for injury or inducing strong behavioural reactions in marine animals, are sounds from airgun arrays, impact pile driving, powerful military search sonars and explosions. With the possible exception of explosions these sounds are generally repeated over many pulses. TSG Noise agreed that there might be a need to consider single explosions separately from the other sounds, partly because of the large amount of energy potentially involved in any one explosion and partly due to the likelihood of a different behavioural response to a single pulse compared to multiple pulses.

Duration of individual sound emissions

TSG Noise considers Southall *et al*.'s *pulse* (Southall *et al.* 2007) to be a good definition of some "impulsive sounds". Southall *et al.*'s definition classifies as a *pulse* all sounds for which the output of a sound level meter on (fast or slow) impulse setting exceeds that on continuous setting by at least 3 dB.

It follows from this definition that a sound whose effective duration is 125 ms (the averaging time for impulse setting) or less is likely to be classified as a *pulse*, whereas a sound of longer than 125 ms is not. Use of this definition would include emissions from airguns, pile driving and explosions as impulsive sounds, but would exclude many sonar pulses. In particular, TSG Noise felt it relevant to include emissions of military search sonar of duration between 1 s and 10 s. For this reason, sounds whose duration up to 10 s are also considered as "impulsive", provided the duration of the gaps between them exceeds the minimum described below.

Duration of gaps between sound emissions

For a sound to qualify as "impulsive", a minimum value of the gap between emissions is proposed of three times the duration of the emission, corresponding to a duty cycle of no more than 25 % (i.e., ratio of repetition time to effective pulse duration (TNO 2011) not less than 4). This factor 4 is based on the following reasoning:

- increasing the factor to (say) 10 would make it possible for sound producers operating close to a 10% duty cycle to avoid monitoring by a small adjustment to that duty cycle;
- decreasing the factor to less than 2 would make it difficult to distinguish each individual pulse from the next one, meaning that such a sound would lack an important characteristic of impulsive sound and would no longer meet the 3 dB criterion for a pulse suggested by Southall *et al.* (2007).

Proposed interpretation of "impulsive sound"

It is proposed that Member States interpret the term "impulsive sound" as a sound for which the effective time duration of individual sound pulses is less than ten seconds and whose repetition time exceeds four times this effective time duration. In this interpretation, it is proposed that all sounds of duration less than 10 s that are not repeated are also impulsive.

3.3 Conclusion on significant impact

The phrase “significant impact” as used in the text of the indicator refers to “serious adverse impacts” on the marine environment. Statistical significance is not relevant in this discussion. The response of Member States to this indicator should initially be to gather relevant information on impulsive sounds. At a later stage, Member States (perhaps supported by advice from TSG Noise) should test the observed indicator values against the “Good Environmental Status” and then conclude whether the total impact should be seen as (ecologically) significant. However, significant impacts have to be well defined addressing which species or regions it may apply to, in such a way that it can be accepted and implemented by all Member States.

3.3.1 Inventory of possible impact of impulsive noise

MSFD descriptor 11 reads: Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment. In order to address this descriptor it is useful to determine when the environment is adversely affected by underwater noise. Table 1 is derived from the OSPAR 2009 noise assessment (and was also used by Tasker *et al*. 2010) and lists all potential negative effects of sound on marine life.

Table 1: Potential negative effects of sound on marine life

Impact	**Type of effect**
Physiological, non auditory	Damage to body tissue: e.g. massive internal haemorrhages with secondary lesions, ossicular fractures or dislocation, leakage of cerebro-spinal liquid into the middle ear, rupture of lung tissue
	Induction of gas embolism (Gas Embolic Syndrome, Decompression Sickness/DCS, ‘the bends’, Caisson syndrome)
	Induction of fat embolism
	Disruption of gas-filled organs like the swim bladder in fishes, with consequent damage to surrounding tissues
Auditory- (Sound Induced Hearing Loss)	Gross damage to the auditory system – e.g. resulting in: rupture of the oval or round window or rupture of the eardrum
	Vestibular trauma – e.g. resulting in: vertigo, dysfunction of coordination, and equilibrium
	Damage to the hair cells in fishes
	Permanent hearing threshold shift (PTS) – a permanent elevation of the level at which a sound can be detected
	Temporary hearing threshold shift (TTS) – a temporary elevation of the level at which a sound can be detected
Perceptual	Masking of communication with conspecifics
	Masking of other biologically important sounds
Behavioural	Stranding and beaching
	Interruption of normal behaviour such as feeding, breeding, and nursing
	Behaviour modified (less effective/efficient)
	Adaptive shifting of vocalisation intensity and/or frequency
	Displacement from area (short or long term)

3.3.1.1 **Determining which impacts are most relevant**

With the current state of knowledge, it is difficult to determine which of the possible above-mentioned impacts of noise can be regarded as the most relevant or important impact; or whether description of one impact can be used to indicate other impacts.

High amplitude, low (frequency < 1 kHz) and mid-frequency (frequency between 1 and 10 kHz) impulsive sounds have caused public concern because of the possible impacts on marine mammals and fish. Sound sources using higher frequency are also omnipresent (in echo sounders, high frequency sonar) and overlap with frequencies used by several cetaceans. The effects of these higher frequencies and the possible development of an indicator for them is discussed in section 5.1.1. Sounds of an impulsive character are also often considered to have more potential to cause physical harm to organisms than sounds that do not have the impulsive character (see Southall *et al*. 2007, Ward 1997). It should be noted that there are different terms in use to describe impulsive sounds; in Southall *et al*. (2007) the term 'pulse' is used to describe sounds with a clearly impulsive character (high peak, rapid rise time). It could be argued whether or not sonar sounds should be called impulsive - according to the definition provided in Southall *et al*. (2007) they would not be called 'pulses'. In the report of TG 11 all sources with high amplitude in this frequency band were considered to be of relevance (see text box 'impulsive sound').

TSG Noise assumed that relevant sounds include those from offshore construction (such as pile driving), the use of airguns during seismic surveys, various types of sonar and explosions. These sources can be very powerful, e.g. in the case of seismic exploration and shockwaves due to explosions. In addition, some activities generating these sounds can persist for considerable periods of time over wide areas. Seismic surveys are routinely conducted over periods of weeks, with repetition rates of several pulses per minute.

Laboratory studies have found both physiological and behavioural impacts from underwater noise in a variety of marine organisms, while field studies have shown behavioural disturbance and in some cases death. Potential impacts of short duration noise encompass the risks of immediate auditory damage or injury of the body from intense sound sources (OSPAR 2009). On population level, however, impacts on the behaviour of marine organisms could be equally or even more important in relation to habitat exclusion, foraging success, health and reproduction. The cumulative impact of behavioural changes poses a further threat from noise. Most researchers consider that the mechanism(s) underpinning the phenomenon of beaked whale mass strandings linked to naval sonar are initially triggered by a behavioural response to acoustic exposure rather than a direct physical impact of acoustic exposure (e.g. ICES 2005).

3.3.1.2 **Quantifying and comparing scale of impacts**

As stated earlier, loud impulsive sounds from sonar, airguns used for seismic surveys and pile driving for offshore construction have caused public concern. For the operators (navies, oil and gas producers and offshore construction companies) it has become necessary to ensure environmentally responsible operations, and thus research efforts have been directed into understanding the impact of these sounds on sea life, often with a focus on marine mammals and to a lesser extent on fish. The impacts of sonar systems have been investigated especially in the United States, but also in European countries, e.g. United Kingdom, Norway, The Netherlands, Italy and Germany. Companies working through the International Association of Oil and Gas Producers continues to fund research programmes into the effects of seismic guns and arrays, and countries around the North Sea have invested in research on the impacts of piling.

Although concerns about the impacts of sound were initially mainly focussed on direct physiological and auditory impacts, behavioural (and to some extent, perceptual) impacts have been given greater attention recently. By now, although most research publications address a single impact, there are a number of publications available that address and compare different impacts of sound on marine life.

Masking is noted as an impact in Table 1 and is addressed by indicator 11.2.1 (continuous low frequency sound).

An inventory of knowledge available on the impacts of sound on marine animals can be found in Southall *et al*. (2007). This publication proposes criteria for sound exposure likely to cause injury in marine mammals and summarizes the data describing impact levels that may cause behavioural changes. Although in most cases no single risk threshold can be given for behavioural impacts, it is clear that levels that induce behavioural responses that can be seen as adverse are at least an order of magnitude lower than those causing injury or other physical effects, e.g. temporary threshold shift (TTS); see Southall *et al.* (2007), table 3 for injury criteria, and e.g. tables 6-9, 18-19 for behavioural criteria for multiple pulses.

Norwegian studies on the impact of seismic surveys on fish (summarised in Dalen 2007) suggest that impact ranges of airguns are several metres for injury but that behavioural changes in some fish species at distances of tens of kilometres may affect catch rates in fisheries. These results have not been repeated elsewhere and further study/analysis would be useful.

In the Atlantic Fleet Active Sonar Training Environmental Impact Statement USN EIS, (United States Navy 2008), an approach using the Risk Assessment Framework, has been used to quantify the impact of sonar operations. Numbers of animals expected to suffer mortality, permanent or temporary hearing loss or behavioural influence are given (see e.g. tables 4.12-4.27). The number of animals expected to show behavioural change is several orders of magnitude larger than the number of animals expected to suffer direct physical impacts. Later studies (Mooney *et al.* 2009, Tyack *et al.* 2011) also confirmed the results of the USN EIS.

3.3.1.3 **Conclusion on significant impacts**

From the studies discussed above a conclusion can be drawn that the number of animals suffering injury through sound and the area in which this occurs are much smaller than the number of animals that show a behavioural change and the area in which this occurs. It is impossible to make a statement whether small numbers of injured animals should be regarded as a greater or lesser impact than a larger number of animals with changed behaviour. However, the two are linked: if sound levels increase, more animals will suffer injuries and more animals, over a larger area, will likely show a behavioural change. It is possible to state that GES can be achieved if impacts are minimised. Minimising the area where a behavioural change will occur is likely to also minimise the area over which animals suffer injury.

As an indicator, behavioural change is possibly more relevant than injury, because it affects a larger part of the population and area; indicator 11.1.1 primarily addresses behavioural change that causes parts of marine animal habitats to become temporarily unavailable. Individual Member States may choose additional indicators that address harmful effects other than behaviour e.g. injury (including hearing trauma, Permanent Threshold Shift) and hearing deterioration (Temporary Threshold Shift).

The EU Habitats Directive requires that Member States manage deliberate disturbance and prohibit injury at the individual level. Some Member States are in the process of defining levels at which this would occur. The introduction of the indicator provides a mechanism for the collective management of noisy activities that potentially cause adverse effects on marine life through behavioural change and other effects. The concept of pulse-block-days (the number of days that in an area (block) a certain threshold (pulse) is exceeded) can be used in marine spatial planning, one of the important tools for implementing MSFD and will enable progress in advising on potential target options, based on real data on the proportion of pulse-block-days.

Table 2 lists the behavioural impacts on marine mammals that may occur. These range from very brief interruptions of normal behaviour to very strong responses such as flight or panic reactions that can lead to stranding.

Table 2 Potential behavioural reactions for free ranging animals, after Southall et al. (2007)

0	- No observable response
1	- Brief orientation response (investigation/visual orientation
2	- Moderate or multiple orientation behaviours - Brief or minor cessation/modification of vocal behaviour - Brief or minor change in respiration rates
3	- Prolonged orientation behaviour - Individual alert behaviour - Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate change in respiration rate - Minor cessation or modification of vocal behaviour (duration < duration of source operation), including the Lombard Effect
4	- Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Brief, minor shift in group distribution - Moderate cessation or modification of vocal behaviour (duration equal to duration of source operation)
5	- Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate shift in group distribution - Change in inter-animal distance and/or group size (aggregation or separation) - Prolonged cessation or modification of vocal behaviour (duration > duration of source operation)
6	- Minor or moderate individual and/or group avoidance of sound source - Brief or minor separation of females and dependent offspring - Aggressive behaviour related to noise exposure (e.g., tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds) - Extended cessation or modification of vocal behaviour - Visible startle response - Brief cessation of reproductive behaviour
7	- Extensive or prolonged aggressive behaviour - Moderate separation of females and dependent offspring - Clear anti-predator response - Severe and/or sustained avoidance of sound source - Moderate cessation of reproductive behaviour
8	- Obvious aversion and/or progressive sensitization - Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms - Long-term avoidance of area (> source operation) - Prolonged cessation of reproductive behaviour
9	- Outright panic, flight, stampede, attack of conspecifics, or stranding events - Avoidance behaviour related to predator detection

TSG Noise noted the following points:

- Although stranding events are very dramatic (category 9), they do not occur often with a clear link to a sound source. The ecological relevance of strandings themselves is probably limited, although sometimes strandings could be indicative of more widespread mortality events at sea.
- Most behavioural responses (in categories 1-6) can be described as interruption of normal behaviour, modified behaviour and adaptive shifting of vocalisation. This is likely to have ecological relevancy, however, these impacts are not always clear and are often difficult to observe. Nevertheless, some marine mammal studies have demonstrated changes in vocal behaviour in response to noise exposure and Norwegian studies have shown change of catch rate of fish exposed to seismic surveys (OSPAR 2009).
- In general behavioural reactions, such as aggressive behaviour, startle response, aversion or anti-predator response are difficult to observe and therefore less suitable for use as an indicator, Changes in reproduction and separation of mothers and dependent offspring can only take place at certain times of the year and is therefore also less suitable as a year-round indicator

Based on these points, TSG Noise proposes that the cumulative effects of sources at levels likely to cause avoidance (category 6 in Table 2) should be used to define a point where GES occurs/does not occur in indicator 11.1.1.

Severe and/or sustained and/or long-term avoidance of an area is likely to be ecologically relevant: In any case of avoidance, the 'normal' distribution pattern will be altered. Thereby, the animal may be forced to stay in a suboptimal habitat, causing limitations to resting, feeding, reproduction or experience density-dependent food limitation. Studies have shown avoidance may occur at low exposure levels (Morton 2002, Miller 2011). Avoidance or displacement has been quantified in a number of recent studies (Miller 2011, Tyack *et al.* 2011, Tougaard *et al.* 2009 a, b, Tougaard 2011). For further considerations on the relevance of different types of behavioural responses, see Tyack (2008).

3.3.1.4 Defining when displacement has significant effects

The impact that is addressed by this indicator is <u>displacement</u>. There is no clear and accepted definition of 'significant displacement' that is useable in all cases and across all species, since displacement may occur in a wide set of circumstances depending on species-specific sensitivity, sound-source properties and regional topography. For example a small fish living on a small patch of coral could already suffer serious effects if it is displaced by 10 m, while for some pelagic species, displacement of a few kilometres may not make a big difference. Within a species, the consequences of a certain amount of displacement will also vary with circumstances.

Displacement is brought about by behaviours that lead to abandonment of an area or habitat and results in changes in dispersion patterns. Such behaviours may incur energetic costs to the animal.

It is not possible to produce maps of distribution of all possible species and their range. Therefore, it is not possible to establish what distance and duration is significant and, based on that, determine a threshold level for the amount of displacement that is acceptable.

TSG Noise therefore suggests that 'significant displacement' relates to the change in distribution of a sufficient proportion of individuals for a time period and at a spatial scale to affect adversely at least local populations of organisms. If it is necessary to use the term 'significant displacement' in the context of GES, then specific case studies will be required. Information that should enable this impact to be assessed and addressed would come from an inventory of "pulse-block-days" or "bang days" registered over the EU's regional seas.

Environmental Impact Assessment (EIA) should consider this issue on a case-by-case basis in order to assess the effects of individual projects and whether mitigation measures are required and possible. The proposed indicator attempts to address the cumulative effects of all relevant noise producing activities. The implications at a population level of the spatial and temporal scale of distribution gaps will depend on the importance of the habitat from which animals have been excluded. European member states are obliged to apply EIAs for new activities, one of the purposes of these EIAs is to assess whether the extent to which animals are excluded from critical habitats is considered acceptable.

3.4 Options and strategies for addressing impulsive noise

TSG Noise advises below on the application of values within Indicator 11.1.1. These are:

1) options on spatial scales (*section 3.4.1*)
2) options on temporal scales (number of days) (*section 3.4.2*)
3) options on sound levels (*section 3.4.3*)

These options are related to impact and to practicality

3.4.1 Options for addressing spatial scale

The size of grid unit (cell) has not been set in Commission Decision 2010/477/EU. Grid size is a very important issue. If the cell is too large, it will lead to an overestimation of the effect of a source (Figure 1 left), whereas if too small, there will an underestimation of effect (Figure 1 right). Ideally grid size should be in approximately the same scale as that of the impacts of the source (the blue ring in figure 1).

TG11 suggested units of approximately ¼ ICES statistical rectangle (15 nmi N/S x 30 minutes E/W). This was a precautionary choice as the empirical evidence for one species (harbour porpoise) indicates average effects of sound from marine piling at ranges beyond 20 km (Tougaard *et al.* 2009b). Other grid units might be the block system used to license oil and gas activities (most North-Western European Member States have such a system). There is also the issue of the rectangles varying in size due the earth being a sphere.

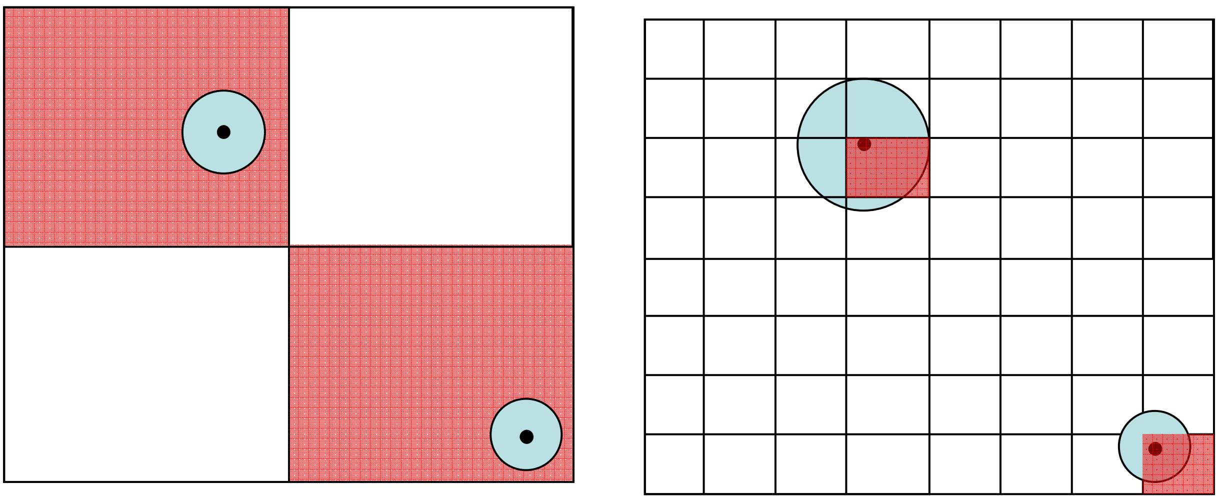

Figure 1. Black dot – source, Blue ring – are where significant impact occurs, red cell – area judged to have a significant impact, if this grid size is used. On the left, grid cells that are too large will overestimate the area with a significant impact. On the right, grid cells that are too small will underestimate the area with a significant impact.

The actual choice of grid definition, and the size of the grid cells, is a choice made by Member States and will be based on practical considerations, e.g. in the UK, data are registered in standard hydrocarbon licensing blocks that can vary from 12 minutes latitude by 15 minutes longitude to 1 x 1 degree. Another option is to base this on the range of 20 km for harbour porpoises, being the only reference that currently exists. A circle with radius of 20 km has an area of ca. 1250 km^2. TG 11 suggested blocks of 15 minutes by 15 minutes. At latitude of 45 degrees North this would give an area of about 550 km^2. For easier interpretation of results in different Member States, TSG Noise would recommend one grid size to be used.

If the grid size is not similar in spatial scale to the impacts of the source, one should take care when evaluating the results: the number of days (or percentage) that activities occur should not be interpreted as a measure of habitat loss (holes in distribution). A correction factor could be applied when comparing results of different grid sizes or for definitions of targets. This correction factor would in principle be based on the ratio of expected impact size to registry grid size.

3.4.2 Options for addressing "number of days" figures

One major problem is to define the threshold where an activity is counted and contributes to the number of days. TG 11 decided to use "bang-days" (better expressed as pulse-block-days). One pulse on a day would turn a grid cell or block "red". For most activities that produce the sounds in question, a single pulse is likely to represent a series (e.g. pile driving, seismic surveys). This is not the case for all sounds (e.g. some uses of sonar or explosions). These later are though relatively rare activities and so the indicator ignores this. A series of pulses spread over multiple days contributes more to the number of days figure than a series produced on one day. An alternative would be to include the number of pulses or the time span over which the activity took place. This though would add considerable complication to both the registration and management of these sounds.

Ideally one would want to define an appropriate time scale on an ecological relevant basis, however, this measure varies by species: Whereas for a small short-lived species exclusion for a few hours may be serious, for some marine mammals a week may not be serious (depending on the species, location and season). Even less is known about the temporal effects. Since no ecological data or studies are available to determine an appropriate time scale, TSG Noise proposes to use "pulse-days" as preliminary practical measure based on precaution. This is a simple and manageable time scale, which in future may change if a scientific basis would become available.

3.4.3 Options for choosing sound sources that exceed 'levels that are likely to entail significant impact'

The Commission Decision 2010 states that: "levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re $1\mu Pa^2.s$) or as peak sound pressure level (in dB re $1\mu Pa_{peak}$) at one metre, measured over the frequency band 10 Hz to 10 kHz". Three options for defining thresholds for sound source level are given below. It is important that all relevant sources are registered, but at the same time ensure that thresholds are established to facilitate a manageable registry.

3.4.3.1 **Option 1. The threshold values of Southall *et al*. 2007**

The first option includes the source levels that were originally suggested by TG 11 for inclusion in indicator 11.1.1. This approach was considered by the UK in their development of indicators and targets for GES.

Trend in proportion of days[1] and their distribution within a calendar year, over areas of 10 min lat and 12 min long and their spatial distribution in which anthropogenic sound sources, measured over the frequency band 10 Hz to 10 kHz, exceed the energy source level 183 dB re 1 μPa² m² s; or the zero to peak source level of 224 dB re 1 μPa² m².

Background:

These chosen source levels are the same as in the TG11-report (Tasker *et al*. 2010). The chosen levels are based on received levels for temporary threshold shift in small cetaceans in most comprehensive review of evidence available (Southall *et al*. 2007)

The received level at which certain impacts are expected to occur is used as a threshold for inclusion of sources

Discussion:

What is attractive in this choice of level for the indicator?

- It is clear and understandable.
- It offers incentive to mitigate: when source levels are brought under the level described in the indicator, an activity 'does not count'. In practice, using current technology, this may be achievable for some coastal sound sources, such as pile driving in shallow water.

What is not attractive?

- Lack of proportionality, no information collected on how loud the source sound actually is, and there can be large differences between sound sources.
- These levels are proposed by Southall *et al*. (2007) as thresholds of *received* level for behavioural disturbance criteria for single pulses. Low-Frequency-Active sonar and tactical mid-frequency sonar are categorised as 'non-pulse' and for these sounds different thresholds apply. For multiple pulses, different thresholds are suggested than the thresholds for single pulses.
- The use of single threshold values may lead to oversimplification.

3.4.3.2 **Option 2. Variable threshold values based on risk assessment**

This approach would determine levels and the way various types of pulses are registered based on available scientific data and an explicit risk assessment framework (e.g. Boyd 2008). This would use, for example, actual data on sound levels and observed displacement/avoidance, and would possibly enable a choice to be made as to when sources should be registered and possibly weight some sources as more significant than others.

However, a choice of threshold for received level alone is not enough - the threshold needed for the indicator is the threshold for the source, and displacement is (by definition) something happening at larger scale. Assuming that the numerical value of the received level, in decibels, might equal that of the source level, will lead to large overestimation of the problem. Some choice will need to be made about the range or size of the area where we consider the behavioural change to be 'displacement', and this choice is not trivial: for fast swimming marine mammals, a temporary avoidance of a source at 100 m is probably not a big problem, the 20 km found in the above mentioned studies is a more serious behavioural change.

After a choice of area size or range has been made, the methodology for making this last step does not need to be difficult, an example is given in annex 5. Once the received sound defining the relevant impact has been defined, it is possible to calculate source levels likely to result in it, depending on the type of source and how the source is used, and making a choice for a propagation model. It is also possible, for cases where the source level is difficult to obtain or not the most practicable measure, to convert the source level to a more convenient proxy such as the equivalent TNT charge mass for an explosion (see annex 5 for the full text).

Any technical approach does not solve one important issue: that in order to use a complete risk assessment framework, a choice needs to be made about the relevant range of disturbance. As noted earlier, due to the highly mobile nature of many marine species and the fact that sensitive areas can be very different over relatively small temporal and spatial scales, adopting a risk-based approach would be challenging.

Background of this proposal:

Levels can be back-calculated from data on behavioural change and a choice of the relevant size impact area (or effect range).

This approach could be more proportional to the actual environmental impact of the pulses.

Some evidence exists for the harbour porpoise. Harbour porpoises are the most abundant marine mammals in the North Sea. There is an indication that they are more sensitive to loud impulsive sounds than other marine mammals.

Discussion

What is attractive in this choice of level for the indicator?

- It is proportional
- It has a firmer scientific foundation

What is not attractive?

- It is complex
- There is limited available information needed to conduct risk assessments in European waters

Although for the long term this approach may be the most suitable, at present, this approach seems too difficult to implement since there are too many uncertainties.

3.4.3.3 **Option 3. Qualitative description of sources**

The third option is simple and straightforward: instead of focusing on acoustic definitions and/or complex calculations, an estimate for threshold levels for relevant sources could be obtained in a two-step approach. The first step is to agree on which sources to include. There is a general agreement about the most relevant type of loud sources that should be included: seismic sources, pile-driving, low and mid-frequency sonar and explosives (TG11: Tasker *et al.* 2010). The second step is to establish a reasonable threshold for these sources. Although TSG Noise agreed that such thresholds could be defined, based on the typical parameters of these sources, no agreement could be reached at this stage on the most appropriate levels that should be used for the most relevant sources (sonar, seismic, piling, explosions). In principle, one would like to ensure that every relevant source is registered, and one could adopt a threshold that is comfortably below these levels (e.g. 10 dB or 20 dB), to avoid missing sources that may be of concern. At the same time, it is necessary to prevent large numbers of irrelevant sources also being registered because that might result in inappropriate responses being taken (if a single threshold was set too low).

For some sources it will be difficult to find an unambiguous definition of (energy) source level, certainly for pile-drivers. See e.g. TNO 2011, appendix B1 and B6.

It is important to realise that the indicator is a pressure indicator, and not a direct measure of impact. If more data become available on the relation between pressure and indicator, the indicator will be implemented as a measure on possible impact on the environment.

At the second meeting of the TSG Noise an additional possibility for the pulse-days indicator was discussed, proposing two separate categories of effect level (e.g. loud and very loud impulsive sounds). Introducing more categories or registering either multiple thresholds or actual levels may help to solve the question about which sources to include. A positive effect of this approach would be that the indicator could be more proportional to the actual pressure on the environment and this approach would also lend itself towards attaining a better understanding about cumulative effects.

Table 3: Suggestion for qualitative thresholds for source levels (Note this table is not definitive, values have not been agreed. Sounds that are considered likely to qualify as a 'pulse' according to the definition of Southall et al. (2007) are characterised by their energy. Other sounds (sonar and deterrents) are characterised by the source level. This table, including justification for the choice of values, will be further worked on during 2012)

Activity	**Threshold for source level**
Seismic survey	Dipole energy source level above threshold value 1;
Sonar	If monopole source level above threshold value 2;
Pile-driving	All pile driving where energy source level is above threshold value 3; or hammer energy[2] is above threshold value 4
Acoustic deterrent devices	If monopole source level above threshold value 5
Explosives	If equivalent TNT charge mass is more than threshold value 6.

Discussion

What is attractive in this choice of level for the indicator?

- Low complexity
- It takes into account average environmental effects on propagation, by suitable choice of thresholds
- Accessible and understandable for non-acousticians
- If levels are well chosen incentive to mitigate may be offered
- Some level of proportionality provided

What is not attractive?

- It is not sensitive to local variations in environmental effects on sound propagation
- There is limited available information, needed to conduct risk assessment in European waters

3.4.3.4 **Conclusion**

Option 2 is the theoretically preferred option, because it has a better scientific foundation. However, the lack of information to justify particular levels means that valid risk assessments would be very difficult to achieve. Option 2 is also very complex making the likelihood of acceptance in EU waters unlikely.

Both option 1 and 3 have advantages and disadvantages. Single threshold values (option 1) can be established, this is a simple and straightforward approach, but the choice of the levels is not scientifically sound and it is difficult to make proportionate.

Option 3 is simple, straightforward and could explicitly describe which sounds should be mitigated; however getting agreement on the levels to mitigate would prove challenging.

[2] For lower complexity, using hammer energy is an alternative as measurements or modelling may not always be available, but this emitted level also depend on the substrate in the area of operations

3.5 Establishment of a register of loud impulsive low-and mid- frequency sound sources

3.5.1 Background

Targets to meet Indicator 11.1.1 will be based on setting trends for the occurrence of loud, impulsive, low and mid-frequency sounds generated by human activity. In order to first understand where and when such sounds occur, and perhaps later to manage their occurrence, it is necessary to establish a mechanism to collate and analyse information on the occurrence (or future occurrence) of these sounds.

A first step is to decide which human activities are likely to generate loud, impulsive, low and mid-frequency sounds above the threshold levels set by the Member State. In the UK, the Department for Energy and Climate Change commissioned a report (Genesis 2010) that compiled the levels and frequencies of sounds produced during various activities associated with oil and gas developments.

3.5.2 Sound Registry

Once a threshold has been decided for sounds likely to “entail significant impact on marine animals” information on the future occurrence and location of such sounds needs to be compiled. This compilation can then be used, if necessary, as a tool to determine the future possible occurrence of loud impulsive low- and mid-frequency pulses, which in turn could potentially be used to manage these occurrences.

At present, information on the occurrence of such sounds is available from a variety of sources. The predominant sources of such sounds in the marine environment are from seismic exploration and from pile driving. In most Member States, seismic surveys are subject either to advance notification or to some form of environmental impact assessment. Most pile driving is also associated with projects subject to environmental impact assessment.

A registry would collate information from these sources into a database structured around the “areas of determined surface” and days of the year. A UK example of the information that is currently available and that could be used in such a registry, together with an analysis of this information is in Annex 6. In terms of collaboration and co-ordination at Regional Sea levels, it would be beneficial if the same areas were used, but this is not critical to the concept – it is more important that information on the occurrence of these pulses is fully captured. If Member States decide to collaborate on a single noise register (for instance to help manage potential trans-boundary effects) then an agreement on thresholds would be needed.

The MSFD does not apply to activities of which the sole purpose is defence or national security (Article 2.2), but Member States shall endeavour to ensure that such activities are conducted in a manner that is compatible, so far as reasonable and practicable, with the objectives of the Directive. However, a registry that leaves out part of the sound sources is not useful as a registry that aims to address cumulative effects of noise. It is, therefore, recommended that loud impulsive, low- and mid-frequency sounds generated by military forces be included in Member States’ monitoring of this indicator on a voluntary basis. Whether or not they use this information to regulate such sources is the responsibility of individual Member States.

4. Ambient Noise (Indicator 11.2.1)

4.1 Introduction

Ambient noise is commonly defined as background noise without distinguishable sources (see Wenz 1962, Urick 1984, Dahl *et al.* 2007, Cato 2008). However, this poses the problem how to deal with identifiable sources that contribute to the local soundscape and that add to pressures. TSGN therefore discussed on a more operational definition of sound relevant to indicator 11.2.1 that is more in line with the term 'soundscape' (see IOQE Science Plan). Following this line of thinking sounds from identifiable sources should be included in recording and analysis in addition to non-identifiable sources. Self-noise, including platform noise and non-acoustic contributions such as electrical self-noise, flow noise, and cable strum may contribute to the recorded signals, but these should be minimized during measurement and should not be considered in the analysis of trends.

Research has shown increases in ambient noise levels in the past 50 years, mostly due to shipping activity. This might result in the masking of biological relevant signals (e.g. communication calls in marine mammals and fish), reducing the range over which individuals are able to exchange information. It is also known that marine mammals alter their communication signals in noisy environments. It is further likely that prolonged exposure to increased ambient noise leads to physiological and behavioural stress. Thus chronic exposure to noise can permanently impair important biological functions and may lead to severe consequences (see Tasker *et al.* 2010).

4.2 Interpretation of indicator 11.2.1

The Commission Decision of September 2010 defines Criterion 11.2 and Indicator 11.2.1 as follows (emphasis added)

> **Criterion 11.2. Continuous low frequency sound**
>
> Indicator 11.2.1: **Trends** in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; **average noise level** in these octave bands over a year) measured by observation stations and/or with the **use of models** if appropriate (11.2.1).

There has been some variation in the understanding of the TG11 report (Tasker *et al*. 2010) and the Commission Decision, probably partly due to variation in understanding of the terminology surrounding the complex issue of underwater sound and its effects. TSG Noise therefore defined the terms used in Indicator 11.2.1 (indicated in bold above).

- **Trends:** the Oxford Dictionary defines 'trend' as 'general direction in which something is developing or changing'. Following this, 'trend' refers to year-to-year (or longer) changes in ambient noise levels.
- **Average noise level:** TSG Noise realised that the term 'average noise level' is not unambiguous; there are different methods to establish a value for an average that are all correct, but lead to different values (see Annex 7). TSG Noise defines 'average noise level' as 'average of the squared sound pressure', since this definition is robust to changes or differences in the duration of individual time samples.
- **Use of models:** Measurements are considered essential to ground truth models. The use of models can strengthen analyses by, for instance, addressing bias introduced by the variability of the spatial distribution of human pressure, and by the natural variability of the environment, and to extend the results of monitoring to poorly or un-covered areas.

Based on these points, TSG Noise suggests the following interpretation of indicator 11.2.1:

Trends in the annual average of the squared sound pressure associated with ambient noise in each of two third octave bands, one centred at 63 Hz and the other at 125 Hz, expressed as a level in decibels, in units of dB re 1 µPa, either measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations.

4.3 Existing ambient monitoring across EU

In this section, an overview is given of the existing or planned monitoring networks for ambient noise. These can be used as a basis for further development to implement the ambient noise indicator.

The LIDO (Listening to the Deep-Ocean Environment) project currently streams ‘real-time’ sound recordings from an array of 13 static autonomous recording devices from around the world’s oceans that can be viewed continuously over the internet. The system provides a unique opportunity to improve our understanding of sound source interactions and potentially to mitigate adverse effects of anthropogenic noise; from a research perspective, the open access to long-term time series of data can reduce costs, help in the design of research protocols and optimize the analysis of results. From the perspective of MSFD’s noise monitoring requirements, the primary advantage of this technology over traditional ‘deploy-and-retrieve’ data loggers is that data can be accessed immediately hence any faults arising with data acquisition can be identified immediately in order to avoid incomplete data sets. Another advantage is the ability of the system to monitor marine life online. LIDO modular architecture of real-time acoustic data management has been built to be easily adaptable not only to a great diversity of data collection platforms (cabled observatories, radio-linked autonomous buoys, towed arrays, gliders, ROVs, AUVs, etc.) but also to diverse situations and configurations that take into account changes of background noise, topography, oceanographic parameters as well as the changing presence of marine mammal species in the area of interest.

The French Hydrographic Office (SHOM) and ENSTA Bretagne conducted a monitoring experiment in the vicinity of the Ushant traffic separation scheme in the western English Channel in 2009 and 2010. Two hydrophones were deployed at about mid-water, one at the edge of the south-going route, another about 10 nautical miles from the same route. The experiment found that, even with high noise levels, measurements are affected by local events that can change sound levels by up to 30 dB dynamics over a period of hours. Deterministic modelling has been implemented by Quiet-Oceans in the whole area, involving in particular vessel automatic identification systems (AIS) and real-time input of oceanographic parameters. The comparison of the predictions of the model and measurements at the hydrophone locations has shown good agreement, predicting in particular the statistical and stochastic content of the ambient noise in this area of high shipping density (Folegot *et al.* 2011).

The European Seas Observatory NETwork (ESONET) has been evaluating marine observatory design requirements in European Seas for many forms of scientific information needs. System designs include data management needs, standardisation and interoperability, social implications, outreach and education, as well as financial and legal aspects of developing such a system. Additionally, several demonstration projects are being carried out, in part, to evaluate various technical options and the implementation of standardised data management approaches.

CEFAS/Defra Monitoring ambient noise in support of the MSFD in UK waters. This project started in early 2011 and it is planned to monitor ambient sound across a number of stations in areas of high shipping density off the UK. This project investigated also to what extent data from Strategic Environmental Assessments (SEAs) and Environmental Impact Assessments

(EIAs) and in particular those from UK MOD sonobuoy deployments (between 1988 – 2008) could be used. The investigation revealed that these sources have only a very limited use, for a variety of reasons and that it was not possible at present to develop information on trends in underwater ambient noise in UK waters based on existing data.

MARNET network. The German Bundesamt für Seeschifffahrt und Hydrographie (BSH) is planning to monitor ambient sound for the MSFD using the MARNET network (Marine Environmental Monitoring Network in the North- and Baltic Sea) of sample stations in the German Baltic and North Seas (Fischer *et al.* 2011). Three monitoring stations will be placed near shipping lanes, two at areas with low pressure and two near areas with wind farms.

There is a variety of data available on ambient noise, collected when monitoring was undertaken for more specific purposes (e.g. monitoring of offshore wind farm construction, aggregate dredging). Results of these studies are documented in the literature and many were presented at an international conference on ambient noise monitoring and management in Southampton, 2011 (Robinson 2011).

4.4 Monitoring scheme for trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS)

4.4.1 Introduction and scope

This section examines the options for monitoring trends in ambient sounds that are characteristic of shipping over time. Issues include location of monitoring systems and sampling considerations.

4.4.2 Widespread or targeted sampling

Monitoring for trends in these sounds is likely to be costly. Therefore any monitoring scheme should be focussed on trying to get the best information in terms of value for money. Trends are most likely to be detectable in areas with relatively large amounts of shipping, and unlikely to be detectable where there is little or no shipping. TSG Noise therefore recommends targeted sampling of areas of high shipping noise.

An extension would be to locate the sensors in different environments representing different soundscape categories. The detailed categorisation could be done on regional or sub regional level to reflect Article 3(5) of MSFD. The sites could cover two main areas: high pressure ones (e.g. near shipping lanes, near any offshore installations that generate noise, etc.) and low pressure areas in order that the proportion of EU's water affected by trends in shipping noise could be better determined.

When defining the positions of the sensors, consideration will also be taken to minimise the risk of loss due to fishing activities, strong currents created by tides and heavy ship traffic. The positions of the sensors may also be adjusted due to military or shipping lane regulations.

The monitoring will have to be applied on a regional scale, as the issue of ambient sound disturbance is trans-boundary. The monitoring concepts across the EU states within a region should be closely aligned, possibly through TSG Noise. This is also a topic where considerable savings could be made if EU Member States co-operated in establishing monitoring schemes.

4.4.3 Use of modelling

It is not possible to get a complete picture of the distribution of sound in the entire marine area from measurements only, because it is not practicable to measure sound at all locations in an appropriate time frame. Hence, the use of models is required to obtain a complete picture of the sound distribution. These models need data that describe the sources of sound, which can be directly measured or based on earlier measurements. Assimilating *in-situ* acoustic measurement is a guarantee to obtain coherence between observation and modelling outputs.

The complementary use of modelling will strengthen the analysis by addressing three main issues:

1) Overcoming bias introduced by known changes in the spatial distribution of human activities, e.g. changes in a ferry route
2) Overcoming bias introduced by the natural variability of the environment (climatic, seasonal change, change in vertical stratification of the ocean and other factors,
3) Extending the monitoring to poorly or un-covered areas.

Noise modelling seems to be an essential complement to measurements for the documentation of trends. Current proof-of-concept studies (e.g. Ainslie 2010, Folegot *et al.* 2011) may help confirm whether methodology is adequate.

Multiple years (e.g. 3-4 years) of combined in-situ monitoring at representative stations coupled to modelling in high-pressure areas and careful statistical analysis (see below) will probably be needed before baselines trends can be established.

4.4.4 Statistical methods for identifying trends and frequencies to be monitored

There are a variety of options for the analysis of data acquired in ambient sound measurements for the MSFD. Some of the main points to consider are:

Frequencies to be monitored. The Commission Decision 2010 prescribes to measure 1/3 octave bands around 63 and 125 Hz. Studies so far indicate that, especially in shallow water, such as the Baltic Sea, ambient noise peaks at higher levels than these two frequencies bands. TSG Noise therefore suggests that higher frequency bands should be added for measurement and analysis than only those described in Indicator 11.2.1. These data can be obtained without substantial extra costs and may prove valuable if in future other frequency bands are found to be relevant.

The data should be processed in 1/3 octave band (centre frequencies) up to approximately 10 kHz with a documentation of SPL vs. frequency range as indicated in figure 2. This analysis could provide important first insights into the spectrum of ambient noise at the different locations and variations in sound pressure levels. The analysis can be applied at various temporal scales. As different types of ships (and other sources) would have specific main frequencies, a very fine scale could help identify sources (see Richardson *et al.* 1995, Ainslie 2010).

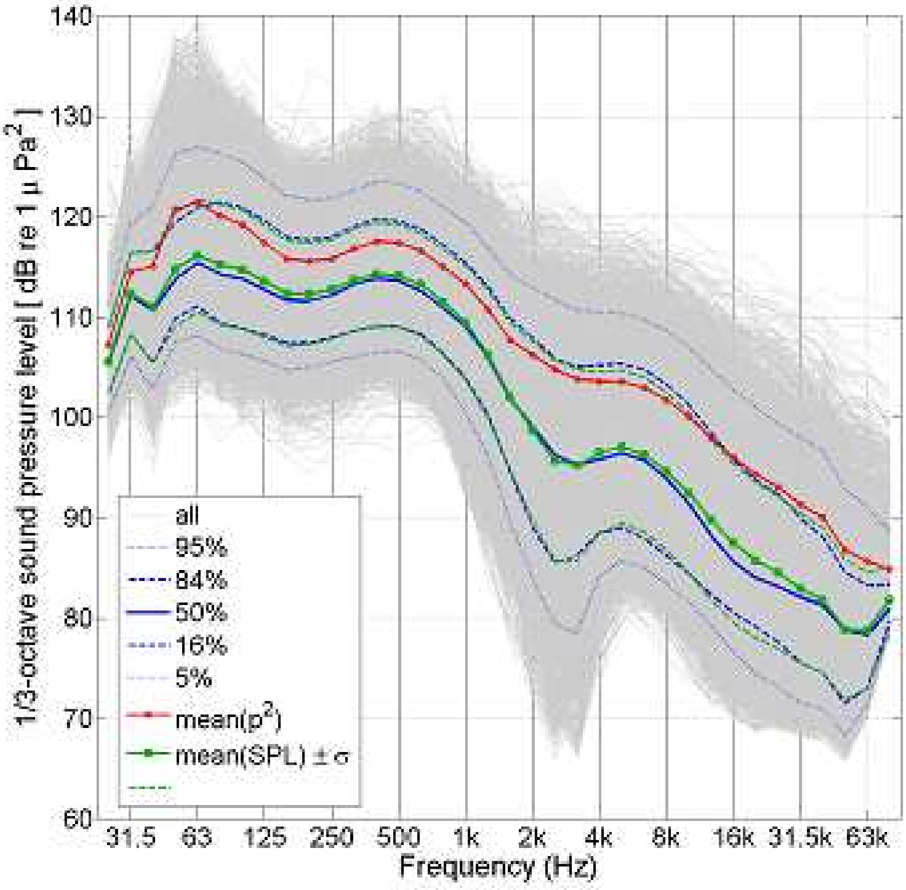

Figure 2. Ambient sound pressure levels in 1/3-octave bands. The results of all individual measurements (6 second snapshots, taken once per minute during a one week period in September-October 2009) are represented by the light-grey lines. The blue dotted, dashed, and solid curves represent the percentiles P5, P16, P50, P84, and P95. The red and green curves represent average values in decibels of the noise levels for averaging over the mean square pressures and averaging over corresponding levels. The green dashed curves represent the levels at ±1 standard deviation from the decibel average. For this dataset, the difference at 100 Hz between the mean square pressure, expressed as a level (red curve), and the median SPL (solid blue curve) is about 7 dB. Measurements were undertaken off the Dutch Coast in 20 m water depth (taken from Ainslie et al. 2011a).

Long-term trends should be investigated using temporal trend analysis in discrete frequency bands and for a variety of these bands up to 1 kHz. This will be the most important analysis to satisfy the requirements of the MSFD. In their analysis of data held by the UK Ministry of Defence, Liddell (2011) made an adequate start by plotting the annual mean received sound pressure levels for the period 1988-2009 for various 1/3 octave centre frequencies (55 Hz – 1150 Hz). It is possible that for MSFD purposes mean levels per month are more suitable but the exact unit requires further investigation. It can be foreseen that the analysis should reflect the statistical spread of the ambient noise, so a documentation of the 5, 50 and 95 percentiles could be most appropriate. For statistical analyses, non-parametric regression analysis is the most suitable tool and can be applied relatively easily (Zar 2010).

Folegot *et al.* (2011) used data processing that includes plotting the proportion of time (and space in case of the use of modelling) versus received levels (called the “S” shaped curves). It has the advantage to characterize the stochastic component of the measurement e.g. the level and period of time where a local source is dominating the measure and would be absent if the hydrophone would have been deployed at a different place.

4.4.5 Reporting format

It will be important that data from each measurement project be made available to compare results across regional seas. It is also strongly advisable to standardise the use of the term 1/3 octave centre frequencies according to TNO (2011). Sharing should be considered on regional and sub-regional level. It is advantageous to share data on regional level using a common data-sharing platform. However, data has to be comparable, thus regional standards on sensor, sensor handling, and signal processing and quality assurance have to be agreed on. One example of data storage and sharing system is MEDIN (Marine Environmental Data and Information Network) in the UK.

4.5 Technical specification of monitoring equipment

4.5.1 Introduction

There are a number of reports in the scientific literature where ocean ambient noise has been measured and reported, and in some cases with descriptions of the recording system used and the analysis methodology adopted. The reader is referred to this literature for background information (Wenz 1962, Andrew *et al.* 2002, Macdonald *et al.* 2006, Chapman and Price 2011, Andrew *et al.* 2011). Though many of these papers relate to noise measurement in deep water, there are many common considerations when considering measurements in relatively shallow European waters

4.5.2 Hydrophone and recording system

4.5.2.1 **Frequency range**

In the interpretation of TSG Noise, the mandatory frequency ranges required to satisfy the indicator are the two third-octave bands with nominal centre frequencies of 63 Hz and 125 Hz. However, most available systems will record over a wider range of frequencies than the above third-octave bands, typically covering the audio frequency range with ease. Therefore, it is desirable that the measurement system covers at least the frequency range 10 Hz to 20 kHz.

The additional range specified above, which is consistent with that proposed Bundesamt für Seeschifffahrt und Hydrographie in Germany, will add little to the operational cost but will provide valuable extra data that will contribute to the knowledge base and assist with evaluation of the monitoring regime at the six-year revision. Note that where other performance parameters may vary with frequency, these should also be determined over the full frequency range of the recording system.

The requirement for unambiguous representation of the signals within the desired frequency band requires the sampling frequency of any Analogue to Digital Converter (ADC) within the recording system to be greater than two times the maximum acoustic frequency of interest. The maximum frequency of interest will be the upper limit of the maximum third-octave frequency band of interest.

4.5.2.2 **Calibration of equipment**

The complete measurement chain (hydrophone-amplifiers-filters-ADC) should be tested before deployment to ascertain that the equipment fulfils its specifications. It is advised to make use of a commercially available hydrophone-calibrator, which provides the hydrophone with a single-frequency tone (commonly at 250 Hz) of well-defined amplitude.

All components of the recording system must be calibrated. The calibration should cover the full frequency range of use and be traceable to national or international standards such as IEC 60565 (2006) or ANSI S1.20-1988 (R2003) ‘Procedures for calibration of underwater electro-acoustic transducers’. The calibration values used should be the result of a measurement by a calibration laboratory or by the manufacturer, and not merely indicative or nominal values indicated by the manufacturer’s design specification. The components that require calibration are:

- *Hydrophone*

  Hydrophone calibration is typically expressed in µV/Pa or dB re 1 V/µPa. Note that at frequencies below the resonance frequency, the hydrophone sensitivity should be independent of frequency, but as a hydrophone approaches its resonance frequency, the sensitivity cannot be considered to be “flat” and is likely to show variations in response.

- *Amplifiers*

  The performance is typically expressed as a gain factor, either in linear terms or in dB. Note that the amplifier gain should be independent of frequency, particularly at the extremes of the operating frequency band.

- *Filters*

  Electronic filters should be used for anti-aliasing purpose but might also be used after amplification to condition the signal before digitisation. The performance is typically expressed as an insertion loss factor, either in linear terms or in dB. By definition, a filter response varies with frequency, and must be characterised over the full operating frequency range of the system. The use of filters may serve a number of purposes, first to provide an anti-aliasing function (a low pass filter designed to restrict the frequency content of the signal before digitisation to below the Nyquist frequency of the acquisition system). Secondly to reduce influence of very low frequency parasitic signals (a high pass filter designed to cut out frequencies of less than 10 Hz which may be generated by non-acoustic mechanisms such as surface motion – such filters are commonly incorporated into commercial hydrophones which have integral preamplifiers). Thirdly to provide some signal equalisation across the frequency range (usually, this involves a high pass filter with a modest slope which is designed to compensate for the frequency roll-off observed in typical ambient noise spectra, thus avoiding saturation of ADC.

  If any of the above filters are used in the system, their performance must be known to correct the data before analysis.

- *Analogue to Digital Converter (ADC)*

  The calibration factor of the ADC must be known. Typically, this factor must be invariant with frequency, but could vary depending on the range setting of the ADC. Note that the scale factor used in generating the data files forms part of the ADC calibration factor.

The system calibration can be undertaken either by full system calibration, or by calibration of individual components. For a full system calibration, the hydrophone is exposed to a known sound pressure field. Recordings of hydrophone output are analysed. For calibration of individual components, the hydrophone is calibrated in the above manner, but the other components are calibrated using known electrical input signals.

A full system calibration where the recorder is deployed in a sound field is preferable. In such cases, the proximity of the body of the recorder unit (which is usually an air-filled case containing batteries and electronics) might give rise to reflected signals, distorting the sound levels.

4.5.2.3 **System Self-Noise**

The self-noise of the system is a crucial parameter when measuring ambient noise. In this context the system self-noise is considered to be the noise originating from the hydrophone and recording system in the absence of any acoustic signal. This is normally expressed as a noise-equivalent sound pressure level in dB re 1 $\mu Pa^2/Hz$ (IEC 60565, 2006). The self-noise varies with frequency and as a result is presented as a noise spectral level versus frequency. The noise equivalent pressure level may be calculated from the system electrical noise using the system sensitivity. Although the system self-noise may be expressed in terms of a noise-equivalent sound pressure level, the origin of the nose is purely electrical from the hydrophone, amplifier and electronic components. It should be stressed that the self-noise described above is distinguished from noise originating from the platform, and mounting.

To achieve acceptable signal-to-noise ratio when measuring acoustic signals, the self-noise equivalent sound pressure level should be at least 6 dB below the lowest noise level to be measured in the frequency range of interest. Knudsen sea-state zero values (Knudsen 1948) at 63 Hz and 125 Hz, which include shipping noise, are approximately 64 dB re 1 µPa2/Hz and 59 dB re 1 µPa2/Hz respectively. Without shipping noise, the noise can be lower. For example Reeder *et al.* (2011) reports approximately 53 dB re 1 µPa2/Hz at 63 Hz and 49 dB re 1 µPa2/Hz at 125 Hz in quiet conditions at the USN Atlantic Undersea Test and Evaluation Center. For a system designed to measure in a low noise situation we recommend a maximum self-noise 6 dB below these values (i.e., 47 dB re 1 µPa2/Hz at 63 Hz and 43 dB re 1 µPa2/Hz at 125 Hz). In other situations, for example close to a shipping lane, the self-noise requirement can be relaxed, depending on the noise level expected.

4.5.2.4 **Dynamic range**

The system dynamic range should ideally be sufficient to enable the highest expected sound pressure levels of to be recorded faithfully without distortion or saturation.

The resolution of the recording should be at least 16-bit, but if possible 24-bit.

4.5.2.5 **Sensitivity**

The sensitivity of the system must be known in absolute terms from a calibration, which should be the result of a measurement. Indicative or nominal values produced at the system design stage are not acceptable. The calibration of the hydrophone and recorder should be done with an overall uncertainty of about 1 dB (expressed at a 95 % confidence level).

It is not necessary to specify the required sensitivity to within a narrow tolerance band, as long as it is accurately known. Taking the required noise performance and dynamic range into account, and considering the performance range of available electronic components, the system sensitivity is recommended to be in the range –165 dB re 1 V/µPa to –185 dB re 1 V/µPa.

4.5.2.6 **Lossless data storage**

To avoid degradation of the data quality, the data format used to store the data should be lossless.

4.5.3 Deployment

4.5.3.1 Deployment method

The deployment method will depend on the local requirements of each individual member state. A bottom-mounted deployment is preferable to a surface deployment to minimise parasitic signals (for example from the influence of surface wave action), to keep the hydrophone away from the pressure-release water-air surface, and to minimise disturbance by surface vessels. A number of typical deployment configurations are possible, many of which are presented in the scientific literature (e.g. Cato 2008, Dudzinski *et al.* 2011, Robinson *et al.* 2011, ANSI S12.64: 2009).

An ideal deployment would allow data to be streamed to shore base, either by cable, or through satellite or modem link (though the latter is likely to limit the data bandwidth to be transmitted). Such a deployment has the advantage of near real-time data availability and enables checks of system functionality to be performed (André *et al.* 2011). However, such configurations are expensive and not readily available commercially at this time. Therefore, it is likely that many deployments will be of autonomous recorders with the data only available periodically after recovery (Wiggins *et al.* 2007, Lammers *et al.* 2008).

Recovery will require either an acoustic release system or a surface buoy deployed from a seabed anchor. Trawl protection may be required for some deployments, depending on the likelihood of disturbance by fishing vessels.

4.5.3.2 Deployment related noise

In addition to the self-noise of the measuring system, the recorded signals may also be contaminated by signals due to "platform self-noise", extraneous signals due to the deployment method for the hydrophone and recording system and its interaction with the surrounding environment (e.g. current, sea-state, etc.). Care needs to be taken in the design of the deployment systems to avoid contamination from noise due to the moorings, or local pressure fluctuations from turbulence due to interaction of the water flow with the measuring system. Often, the presence of contamination cannot readily be detected *a priori* even though it is present. This makes it very difficult to remove the influence of contaminating parasitic signals (Cato 2008, Harland 2008, ANSI S12.64: 2009, Robinson *et al.* 2011, Dudzinski *et al.* 2011).

The following list shows some of the more common sources of unwanted parasitic signals that contribute to the platform self-noise of the deployed system in addition to the electrical self-noise in the hydrophone and recording system.

Flow noise

Any flow relative to the hydrophone or cable can induce turbulent pressure fluctuations at low frequency that will be sensed by a pressure sensitive hydrophone (typically < 100 Hz). Methods of reducing flow induced noise include locating the hydrophone close to the seabed where flow is reduced, use of drifting buoys and the use of mechanical fairings, often in spiral or helical form around cables and housings (Urick 1983, Ross 1987, Cato 2008).

Hydrophone cable strum

Cable strum occurs when cables are pulled taught by the action of currents, and the cable is caused to vibrate by the action of the water flow, producing parasitic low frequency signals. This is similar to the "aeolian harp" effect, or the singing of telephone wires in the wind. For typical cable diameters and current speeds, signal frequencies are of the order of 10 Hz (1 cm diameter cable in 1 knot of current produces a frequency of 9 Hz). The use of bottom-mounted deployments, decoupling of the hydrophone from suspension cables using compliant couplings (eg elastic rope), and the use of cable fairings will help to minimise the problem (Urick 1983).

Mechanical noise

This includes (i) debris and/or sediment impacting the hydrophone; (ii) biological abrasion noise; (iii) hydrophone and cables rubbing against each other. Any opportunity for parts of the mooring system to impact against each other will cause noise, which may be audible, especially if it involves metal parts. To minimise the problems:

- avoid metal coming into contact with metal such as with shackles.
- avoid the use of chains in the supports.
- avoid placing hydrophone too close to seabed.

Hydrostatic pressure fluctuations

Any system deployed from the surface will have the potential to be affected by wave action, which will cause low frequency (but high amplitude) pressure fluctuations which may saturate the ADC in the recorder. The best solution to this problem, if the hydrophone is to be deployed close to the seabed, is to mount the hydrophone at the seabed rather than the sea surface, using a bottom-mounted frame or sub-surface buoy arrangement.

4.5.4 Auxiliary measurements

It is beneficial to record any auxiliary data that may be relevant, since these may be correlated with the measured noise levels during analysis. Some of the information may be obtained from other sources (for example, weather data). If measured locally, this may require the deployment of auxiliary equipment. Depending on the availability this may or may not be possible. Relevant auxiliary data may include:

- Sea-state
- Wind speed and associated measurement height
- Rate of rainfall and other precipitation, including snow
- Water depth and tidal variations in water depth
- Water temperature and air temperature
- Hydrophone depth in the water column
- GPS locations of hydrophones and recording systems
- Seabed type.

5. Future Work

5.1 Assessment of the need to develop criteria and indicators on other aspects of underwater noise and other sources of energy

The two indicators of underwater sound described in the Commission Decision of September 2010 do not cover all sources of anthropogenic sound or other forms of energy input, nor do they explicitly describe the impacts of anthropogenic underwater noise on biota. In this chapter, TSG Noise identifies and prioritises other aspects of underwater noise and other sources of energy for which indicators could be developed practically in the near future.

The TSG Noise decided that high-frequency impulsive sounds and electromagnetic fields should be given priority for the development of indicators, whereas additional important aspects are mentioned for further consideration, research and development. For both energy sources further evidence as well as possible proposals for indicators could be considered at the next meeting of TSG Noise.

5.1.1 Medium and high frequency impulsive sounds

Vertical observing echo sounders and horizontal observing fish finding sonar systems on small vessels typically use frequencies between 50-180 kHz and/or just over 200 kHz (Tasker *et al.,* 2010). Use of echo sounders, particularly on leisure boats, is both increasing and is unregulated. Leisure boats usually have sounders in the frequency range of 50-200 kHz. Usually these high frequency sounds do not propagate far due to the higher absorption of sound at these frequencies (see e.g. Ainslie 2009, Ainslie and Dekeling 2011), therefore the affected volume of sound insonification is relatively small compared to horizontal-looking sonar thus lowering the probability of affecting marine life. Smaller vessels tend to operate in coastal areas throughout the EU. There has been little research on the effects of these echo sounder systems and the scientific evidence for adverse effects is limited. However, these waters are often important for some marine mammals, such as the harbour porpoise. These animals use frequencies up to about 180 kHz for communication and orientation and thus there is an overlap in frequency usage (Tasker *et al*. 2010).

It would be useful to evaluate the use and prevalence of high-frequency echo sounders mounted in small vessels and to consider their potential impacts on cetaceans (and other marine life) prior to suggesting an indicator. Several mitigation measures seem possible for these echo sounders.

5.1.2 Electromagnetic fields

A number of marine species including fishes, marine mammals, sea turtles, molluscs and crustaceans are sensitive to electromagnetic fields and use them for e.g. orientation, migration and prey detection (see Poléo *et al*. 2001, Gill *et al*. 2005, OSPAR 2008). Some marine fish species use the earth's magnetic field and field anomalies for orientation especially when migrating (Fricke 2000). Artificial magnetic fields may impair the orientation of fish and marine mammals and affect migratory behaviour. Field studies at the offshore wind farm Nysted on fish provided evidence that power cables can change the migration and behaviour of marine fish (Klaustrup 2006). Elasmobranch fish can detect fluctuating magnetic fields that are weak compared to the earth's magnetic field (Poléo *et al*. 2001, Gill *et al*. 2005). Marine teleost (bony) fish show physiological reactions to electric fields at minimum field strengths of 7 mV m^{-1} and behavioural responses at 0.5-7.5 V m^{-1} (Poléo *et al*. 2001). Elasmobranchs (sharks and rays) are more than ten thousand fold more electrosensitive than the most sensitive teleosts. Gill and Taylor (2001) showed that the spurdog *Scyliorhinus canicula* avoided electric fields at 10 mV m^{-1}. In regard to effects on fauna it can be concluded that electromagnetic fields are detected by a number of species and that many of these species respond to them. However, threshold values are only available for a few species and it would be premature to treat these values as general thresholds.

It is reasonable to assume that in the future more power cables will be required to allow exchange of electricity within the European grid. There will be an increasing number of cables entering service as the number of offshore wind farms increases in various European states. Beside the cables transporting electricity to the grids, wind farms also have cables connecting the turbines with each other and with transformer stations. In the medium term, development of marine renewable energy projects (wave and tidal energy) will create a similar requirement for new cables. TSG Noise could consider whether an indicator would be helpful for this form of energy input, or whether it might best be addressed through mechanisms such as SEAs and EIAs. Further sources of electromagnetic fields are return currents that are fed through water. This power technique is often used near cost and in archipelagos and give rise to electric currents and thus voltage differences.

5.1.3 Combined mapping of sound levels and sensitivity of marine life

In the light of MSFD Article 1.2(b) "prevent and reduce inputs in the marine environment, with a view to phasing out pollution as defined in Article 3(8), so as to ensure that there are no significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea." the input on the environment as well as the impacts on related biota needs to be known. Mitigation measures without a reasonable aim can be expensive and time-consuming; furthermore it could handicap industrial development in the marine environment. On the other hand mitigation measures which are not sufficient may increase the risk for biota.

There are numerous examples of sound-induced effects recorded for cetaceans, either in controlled situations, or opportunistically. These effects cover almost all major families/super families and include either behavioural effects or auditory threshold shifts. Broad or narrow band continuous sounds, as well as pulses, have been documented to cause effects ranging from slight behaviour change, to activity disruption, avoidance or abandonment of preferred habitat, masking effects, including overlap between passive perception (orientation) and communication (see Clark *et al*., 2009 for background), temporal and permanent hearing threshold shifts as well as impacts on non-auditory systems etc., either short or long term.

Acoustic mapping of areas of interest (ambient noise trends and sound budgets in regional sea areas) in combination with the application of seasonal presence and abundance models for each (group of) species ideally would allow for establishing received levels of sound for different species. This is in line with the description of an exposure assessment within the Risk Assessment methodology (Boyd 2008), also described in annex 5. It offers a combined evaluation of the two existing indicators.

To make a complete risk assessment, one also needs data on the relation between exposure and effect. These data are only scarcely available at this point, although recently, Gannier and Mifsud (2011) suggested that the use of perceived levels would enable an estimate of sound-induced effects for cetaceans. This would be an exposure effect assessment according to Boyd (2008).

5.1.4 Further issues

The following kinds of energies are weighted as less important or covered elsewhere but may become more important with more information.

Air-based mechanical energy and light: There are growing concerns that offshore wind farms can have detrimental impacts on birds. However this issue is currently being addressed by OSPAR and the outcome of this process should be awaited before making any decisions. In addition, this is not an emission of underwater energy, the text of the MSFD does not make explicit whether the indicator covers only underwater energy.

High frequency acoustic deterrent devices: (ADDs or 'pingers') and Acoustic Harassment Devices (AHDs or 'seal scarers') are designed to displace porpoises/dolphins and seals, respectively, from the immediate vicinity of fishing and aquaculture gear and construction work such as impact pile-driving of offshore wind farms. Especially AHDs that produce loud signals in important frequency ranges for marine mammals have a potential to cause local effects in distribution and hearing impairment. Low frequency acoustic deterrents are already included under Indicator 11.1.

Particle motion: Construction noise like pile driving, sound pulses from airgun arrays and several other sources create high levels of sound pressure and acoustic particle motion in the water and seabed. Many fish and invertebrates respond to particle motion as well as to sound pressure as more than 30 years of research has demonstrated (for overview see; Sand and Karlsen 2000, Ona *et al*. 2007, Sand *et al*. 2008). The consequences are that, in order to understand and explain behavioural changes in fish and invertebrates from various sound sources, adequate sensors have to be used to measure the true stimuli, which in addition to acoustic pressure include the sound kinetic components as particle acceleration and velocity. New measuring platforms, and extensions to existing ones, should consider including velocity or acceleration sensors if intended for use close to high amplitude sound sources.

5.2 Further research needs

There are many publications that address research needs for underwater noise. In this chapter TSG Noise suggests three areas for further research, focussed on helping Member States to implement MSFD.

5.2.1 Working towards a better understanding of the impacts of noise on biota.

Understanding the actual impacts noise has on biota will help Member States to specify GES and applying the appropriate mitigation measures, if necessary.

There have been a number of studies of the effects of noise on marine biota. These studies have tended to be at the level of the individual organism and have been heavily biased towards marine mammals (particularly cetaceans), with fewer studies on fish and other animals. This bias probably reflects the high level of protection of several marine mammal species. If we are to understand effects and the population and ecosystem level (the level addressed by MSFD) then further modelling and research is required for all marine biota. It is also worth noting that human activities, such as emitting underwater sound, do not occur in isolation, and methods to account for cumulative and synergetic effects also need to be developed.

Recently, a large-scale initiative was launched to address the issue of ocean sound. This initiative, called the International Quiet Ocean Experiment (IQOE), is supported by the Scientific Committee on Oceanic Research (SCOR) and the Partnership for Observation of the Global Oceans (POGO). The IQOE intends to provide a framework for a decade-long project of research, observations, and modelling, aimed at improving our understanding of generation, propagation and reception of sound in the ocean and its effects on marine organisms. The project will include carefully designed observations exploiting situations of varying sound inputs in conjunction with detailed model analysis. TSG Noise sees a benefit in MSFD liaising closely with IQOE to provide a capability for global monitoring of GES. A comprehensive IQOE research plan will be published mid 2012.

5.2.2 Research on the development of additional indicators for abovementioned issues

Research is needed on the development of criteria and indicators on other aspects of underwater noise and other sources of energy. Priority should be given to the subjects described in 5.1.1, 5.1.2 and 5.1.3

6. Conclusions and roadmap

6.1 Principal aim of the work of TSG Noise

The EC decided in 2010 that guidance was needed to help member states implement the indicators that were chosen in the Commission Decision of 2010 (EC 2010). TSG Noise therefore has focussed on clarifying the purpose, use and limitation of the indicators and described methodology that would be unambiguous, effective and practicable. For both the impulsive and ambient noise indicators it has been possible to make significant progress towards practical implementation of the indicators, and most ambiguities have been solved. This is further explained below for these indicators, including the remaining issues that need to be solved. TSG Noise further has identified knowledge gaps and future work, and advises on the way forward in 2012.

6.2 Impulsive Sound

6.2.1 Interpretation of the indicator on Impulsive Sound

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

TSG Noise evaluated the terminology in the Commission Decision and concluded on the following clarification / interpretation of indicator 11.1.1 to avoid misinterpretation:

The proportion of days and their distribution within a calendar year, over geographical locations whose shape and area are to be determined, and their spatial distribution in which either the monopole energy source level (in units of dB re 1 µPa^2 m^2 s), or the zero to peak monopole source level (in units of dB re 1 µPa^2 m^2) of anthropogenic sound sources, measured over the frequency band 10 Hz to 10 kHz, exceeds a value that is likely to entail significant impact on marine animals (11.1.1).

6.2.2 Aim of the indicator

TSG Noise agreed that the impact that is addressed by this indicator is "considerable" displacement. This means displacement of a significant proportion of individuals for a relevant time period and spatial scale. TSG Noise has not determined what could be seen to be a 'significant proportion', since this information is not available yet.

Information that should enable this impact to be assessed and addressed would come from an inventory of "pulse-block-days" registered over the EU's regional seas.

The indicator is addressing the cumulative impact of sound generating activities and possible associated displacement, rather than that of individual projects. It provides for the first time a tool to register and ultimately manage underwater sound, and thus enable use for e.g. marine spatial planning. Environmental Impact Assessments (EIA) can be used to limit the environmental impacts of individual projects on a much smaller spatial scale. TSG Noise noted also requirements of other European legislation that restricts the effects that underwater sound may have on certain marine animals. Options for mitigation are also included as part of EIA procedures.

6.2.3 GES and Targets on Impulsive Sound

At the moment it is difficult to provide a more specific description of GES beyond the text of the Directive: *Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.* This is due to insufficient knowledge on the cumulative impacts of impulsive sound on the marine environment. There are different views between member states whether to include individual cases or whether GES should only be determined at ecosystem scale.

The initial purpose of this indicator will be to assess the pressure, i.e. an overview of all loud impulsive low and mid-frequency sound sources, through the year and through areas. This will enable MS to get an overview of the overall pressure from these sources, which has not been achieved previously. A necessary follow-up in future years would be to evaluate effects on biota and set targets and potentially take measures. Indicator 11.1.1 is a pressure-indicator, and a possible future target would thus be in the form of a threshold of, or a trend in, the proportion of days when impulsive sounds occur and in their spatial distribution.

6.2.4 Register of Impulsive Sound

A first step is to establish the current level and trend in these impulsive sounds. This should be done by setting up a register of the occurrence of these impulsive sounds. TSG Noise recommends that MS work together to set up such a register, both at the regional level and the EU level. TSG Noise evaluated all aspects that need clarification and provided initial guidance on determining sources that need to be registered, spatial and temporal scale. TSG Noise considered whether quantitative relation between indicator and pressure (proportionality) could be improved

6.2.5 Sound Sources

TSG Noise considered several approaches for addressing this indicator. The approaches were based on i) single thresholds, ii) a risk assessment framework or iii) an inventory of sources. Most TSG Noise members agreed that the third option would be the most pragmatic and practical for the moment and that in the next 6 years the option based on the risk assessment framework (second option) should be further developed particularly following information that further research should gather.

TSG Noise identified the following sound sources as most important to be taken up in the register. A definitive choice of threshold levels as proposed in the third option could not be made at this time; it was also realised that for some sources it would difficult to find an unambiguous definition of (energy) source level.

Table 4: Indicative list of activities and sources likely to generate impulsive sounds between 10 Hz and 10 kHz that may cause significant impact on marine animals.

Activity	**Type of source**	**Parameter chosen to characterise source**
Seismic survey	air gun array	Energy source level
Sonar search	low or mid-frequency search sonar	Source level
Offshore construction	pile driving	Source energy level, acoustic energy or hammer energy
Use or disposal of explosives	explosion	Equivalent TNT charge mass
Aquaculture, fisheries	Low or mid-frequency acoustic deterrents	Source level

6.2.6 Spatial scale

Ideally grid size should be in the same approximate spatial scale as the scale of the impacts of the source, however, this varies per species and source. The actual choice of grid definition, and the size of the grid cells, is a choice made by MS and often will be based on practical considerations, (e.g. in the UK, data are registered in standard hydrocarbon licensing blocks of 12 minutes latitude by 15 minutes longitude). If the grid size is not in the same spatial scale as the impacts of the source, a correction factor can be applied when comparing results of different MS or for definitions of targets.

6.2.7 Temporal scale

The indicator uses days as the basic temporal unit although the significance of any impact is likely to be determined by the proportion of days and their spatial distribution. Ideally one would want to define an appropriate time scale for impacts that is based on an ecologically relevant level, however, this will most likely vary greatly between species. TSG Noise proposes to use days as the basic unit, since large scale displacement on a one day basis could be regarded as potentially significant for marine mammals, and that distributional gaps lasting one day would likely also scale to other organisms that move less far.

6.2.8 Proportionality

The indicator as described in the Commission Decision does not provide explicitly for proportionality. This could however be addressed to some extent by making a provision for a register that classified sound sources into more than one category (e.g. ‘loud’ and ‘very loud’).

6.3 Ambient noise

6.3.1 Interpretation of the indicator on Ambient Noise

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

TSG Noise evaluated the terminology in the Commission Decision (EC 2010) and concluded on the following clarification/interpretation of indicator 11.1.2 to avoid misinterpretation:

Trends in the annual average of the squared sound pressure associated with ambient noise in each of two third octave bands, one centered at 63 Hz and the other at 125 Hz, expressed as a level in decibels, in units of dB re 1 μPa, either measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations.

6.3.2 Trends

TSG Noise refers to the explanation of the Oxford Dictionary, which defines ‘trend’ as ‘general direction in which something is developing or changing’. Following this, ‘trend’ refers to year-to-year (or longer) changes in ambient noise levels.

6.3.3 Average noise level

During the meeting in February 2011, TSG Noise discussed what kind of average noise level would be appropriate. Details of this await further consultation. As a first approach TSG

Noise suggests using the mean square pressure. Unlike other types of averaging, it is expected to be robust to changes or differences in the duration of individual time samples.

6.3.4 Models and measuring

Noise modelling should ideally be done together with in-situ measurements. The use of modelling will strengthen the analysis by overcoming bias introduced by changes in human activities or the by the natural variability of the environment and will extending the monitoring to poorly or un-covered areas.

6.3.5 GES and Targets on Ambient Noise

At the moment it is impossible to define those elevations of ambient noise from anthropogenic sources that would cause the marine environment to not be at GES. This is due to a lack of knowledge on the impacts of elevated ambient noise on the marine environment.

The TSG cannot therefore advise on a level of ambient noise that could be set as a target for this indicator. However, since shipping is one of the largest contributors to low frequency ambient noise, the International Maritime Organisation (IMO) will be involved in potential future measures. Recently, the IMO has made general recommendations on technical possibilities to reduce shipping noise and agreed that uncertainty should not preclude working on the issue of quieting technologies for commercial ships. Under IMO, there is an active correspondence group that has recently published a recommendation paper with non-mandatory technical guidelines towards reducing ship noise.

There are other fora working on this issue, for example the Scientific Committee of the IWC (the International Whaling Commission) that has endorsed targets to reduce shipping noise; the SCOR/POGO-project International Quiet Ocean Experiment has recognized the possible need to reduce the contribution of shipping to elevated ambient noise, and have suggested a long-term research program to determine whether in the future, levels and targets for GES are likely to require a decreasing trend in shipping noise.

6.3.6 Monitoring of Ambient Noise

A first step is to establish the current level and any trend in ambient noise. This should be measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations.

TSG Noise recommends that MS start a measurement programme as soon as possible in order to be able to define the current levels and trends in ambient noise (from shipping) by 2018

6.4 Methodological standards

There are no internationally accepted standards for terminology used to describe underwater sound. In 2010, in The Netherlands, Germany and the United Kingdom, collaborative projects were started to define and agree the terminology of underwater sound. The results of this cooperation are described in TNO (2011), and will likely be used as a basis for formal (ISO-) standards. Given the lack of a formal standard at present, TSG Noise recommends that Member States use the proposed standard terminology of TNO (2011).

6.5 Knowledge gaps and future work

6.5.1 Knowledge gaps

TSG Noise realises that there are a lot of unknowns around underwater energy and noise. TSG Noise has not attempted to identify all knowledge gaps around this issue, but focussed on that knowledge that is most urgently needed by MS in order to implement the indicators and further implementation of the MSFD, in particular the determination of Good Environmental Status and target setting.

The most relevant issues are:

- Better understanding of the impacts of noise on biota, in order to help MS to specify GES; MS are required to review their marine strategies six years after the initial establishment, which means by 2018.
- Research on issues that have not been addressed yet, for example high-frequency masking, effects of light, electromagnetic fields, etc.

6.5.2 Other sources of energy and further research

High-frequency impulsive sounds and electromagnetic fields should be given priority for the development of indicators. For both energy sources further evidence as well as possible proposals for indicators could be considered in 2012.

Additional important aspects are mentioned for further consideration, research and development.

- Further research is needed on in particular on the following subjects:
- Understanding the impact of noise
- Sound induced effects expressed in terms of received levels
- Particle motion.

6.6 Road Map for work in 2012 and beyond

The TSG Noise has identified potential priority work items for support to the implementation of Descriptor 11 during 2012/2013. These work items will be taken up in the work programme for TSG Noise for 2012/2013. In 2012/2013, the main focus of TSG Noise will be on developing a practical guidance for monitoring and noise registration.

6.6.1 Monitoring Guidance

Subjects that should be addressed in the monitoring guidance are:

<u>For impulsive noise</u>

1) Test and further develop the noise register
    - Collect data from MS on impulsive noise
    - Review the data and the way in which they are stored
    - Develop a proposal for the establishment of a common register.
2) Develop a proposal for MS on how to set a baseline on the number of days indicator

<u>For ambient noise</u>

3) Develop guidance on how to measure ambient noise
    - Type of devices
    - Frequency range that should be recorded

- Number, location and distribution of measuring locations
- The use of sound mapping and modelling

4) Develop guidance on how to establish a baseline level and review to which extent current monitoring networks and existing data can be used for the purpose of the baseline assessment

For both types of noise

5) Develop guidance for MS on how to interpret the results

6.6.2 Assist in future target setting

6) TSG Noise will develop a guidance addressing several ways in which MS may and describe GES in future and set targets including, where possible, examples.

6.6.3 Other tasks

7) Assessing the need and developing additional indicators on high-frequency impulsive sounds and electromagnetic fields

   These two types of energy were prioritised in 2011 by the TSG Noise. In 2012 a proposal for an indicator and a justification for addressing these sources should be developed and presented to the WG GES.

8) Identify indicator species for defining thresholds for the different impacts (e.g. physical injury and relevant displacement as regards impulsive sounds; zones of masking as regards continuous sources)

9) Develop guidance on acoustic mapping for area-specific sound budgets and species-specific impact areas.

10) Collect further information on the impact of impulsive noise and ambient noise and on cumulative noise effects

11) Develop recommendations on noise reduction and mitigation measures.

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List of annexes

Annex 1: Terms of Reference (ToR) for the TSG Noise

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
ENVIRONMENT
Directorate D - Water, Chemicals & Cohesion
ENV.D.2 - Marine

Document MDs
Spa, 2 December 2010

Agenda Item 2.1.3

Terms of reference of the technical subgroup on Underwater noise and inputs of other forms of energy

(version 23 November 2010)

The technical subgroup will address the following issues:

1. Identify and review existing data and monitoring methods on underwater noise

The work should be based on a review of experiences within Member States for different sources of noise and the knowledge within the scientific community in this field. It should be related to the two identified criteria and associated indicators in the Commission decision:

11.1. 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 1µPa^{2}·s) or as peak sound pressure level (in dB re 1µPa**peak**) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1)

11.2. Continuous low frequency sound

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

2. Develop proposals for methodological standards for registering loud impulsive sounds

The proposed methodological standard must be feasible and implemented with reasonable efforts. It should describe how to come to proportion of days and their distribution within a calendar year as well as their spatial distribution of anthropogenic sound sources.

3. Develop proposals to monitor low frequency continuous sounds

The proposed monitoring must be feasible and implemented with reasonable efforts. It should describe what type of instruments (technical specifications) to be used for which frequencies, how to monitor continuous low frequency sound, sampling method, filtering, statistical analysis methods, etc. The proposal should take into account differences in physical features in the European seas with respect to configuration, depth, morphology which influence propagation. For assessments the use of models to develop 'sound maps' needs to be considered.

4. Assess the need to develop criteria and indicators for other forms of energy

The Decision on criteria and methodological standards on GES mentions also the need to develop additional scientific and technical progress to support the development of criteria related to the impacts of other forms of energy such as thermal energy, electromagnetic fields and light. Questions need to be answered such as: What are the potential impacts? How to monitor the pressure? Is there a need to develop this into a GES indicator? What are appropriate indicators? The subgroup should recommend proposals for further criteria, if required, in this respect.

5. Good Environmental Status, targets and indicators

The technical subgroup provides a platform for sharing best practices on the development of what constitutes Good Environmental Status (characteristics of GES), environmental targets and associated indicators in relation to underwater noise. They should take into account differences in physical features in the European seas with respect to configuration, depth, morphology which influence propagation. This can inform the work being taken forward at the level of each marine region and subregion (where possible in the context of regional sea conventions) and at national level.

6. Research needs and recommendation for future work

Additional scientific and technical progress is still required to support the further development of criteria and associated indicators related to this descriptor, especially in relation to relevant noise and frequency levels that have an impact on marine life as the MSFD requires that the ‘introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment’. The propagation and receiving of underwater noise is thereby relevant. The subgroup would need to consider whether, due to species specific noise sensitivities, it may be necessary to develop a suite of impact criteria and associated indicators. The subgroup should recommend proposals for further research priorities in this respect.

7. Reporting

Interim reports will be required prior to the meetings of the WG on GES. These brief reports should indicate the status of the subgroup work. The final report by itself can be short. It should explicitly address the issues identified in the ToR. The substance of the work will be in annexes; these can be much more detailed with recommendations how to apply criteria indicators and methodological standards.

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Photo: The TSG Noise at its first meeting in February 2011 in Delft.

Annex 3: Glossary

This glossary defines terms used for our interpretation of the two indicators. For a more complete list of definitions the interested reader is referred to (TNO 2011). For some sources it will be difficult to find an unambiguous definition of (energy) source level, certainly for pile-drivers. See e.g. TNO 2011, appendix B1 and B6. It should be realised that all definitions related to source level (including energy source level, monopole and dipole source level) are still under development and definitions that are proposed here should be seen as preliminary working definitions.

Term	Proposed definition	Notes
Ambient noise	For a specified signal, all sound in the absence of that signal except that resulting from the deployment, operation or recovery of the recording equipment and its associated platform.	If no signal is specified, all sound except that resulting from the deployment, operation or recovery of the recording equipment and its associated platform. See also para 4.1 where the definition of AN is explained.
Continuous sound	imprecise term meaning a sound for which the mean square sound pressure is approximately independent of averaging time	From TNO, 2011
Dipole energy source level	The value of 10 $\log_{10}(\int p_{FFt}^2(r,t)dt\ r^2/p_{ref}^2\ r_{ref}^2\ t_{ref})$, where $p_{FFt}(r,t)$ is the far-field instantaneous acoustic pressure that would exist at distance r in a specified direction from the source plus its surface image if placed in a hypothetical ideal medium and driven with identical motion of all acoustically active surfaces as in the real medium. The hypothetical medium is a lossless uniform medium of the same characteristic impedance as that at the source location in the true medium, and extending to infinity in all directions.	Based on TNO. 2011 (scenario A of the definition for “energy baffled source level” in Appendix B)
Energy source level	The value of 10 $\log_{10}(\int p_{FFt}^2(r,t)dt\ r^2/p_{ref}^2\ r_{ref}^2\ t_{ref})$, where $p_{FFt}(r,t)$ is the far-field instantaneous acoustic pressure that would exist at distance r in a specified direction from the source if placed in a hypothetical ideal medium and driven with identical motion of all acoustically active surfaces as in the real medium. The hypothetical medium is a lossless uniform medium of the same characteristic impedance as that at the source location in the true medium, and extending to infinity in all directions.	Based on TNO. 2011, ESL_2, there is an alternative definition provided (ESL_1) that leads to same numerical value. The quantity $\int p_{FFt}^2(r,t)dt\ r^2$/is referred to in Ainslie 2010 and TNO 2011 as the “energy source factor”.
Equivalent TNT charge mass	The explosive mass converted to the mass of a TNT charge that would deliver the same detonation energy, can be calculated using $\mathbf{M_{TNTe} = (E^d_{exp}/E^d_{TNT}) \cdot M_{exp}}$	See UN-ODA 2011, International Ammunition Technical Guideline IATG 01.80:2011[E] M_{TNTe} = equivalent TNT charge mass (kg) E^d_{exp} = specific detonation energy of explosive (J/kg)

Term	Proposed definition	Notes
		E^{d}_{TNT}) = specific detonation energy of TNT (J/kg) M_{exp} = mass of explosive (kg)
Impulsive sound	a sound for which the effective time duration of individual sound pulses is less than ten seconds and whose repetition time exceeds four times this effective time duration. In this interpretation, it is proposed that all sounds of duration less than 10 s that are not repeated are also impulsive	This report, para 3.2, textbox 3
Mean square sound pressure	synonym of **mean square pressure;** the quantity p_{RMS}^2	From TNO, 2011
Monopole energy source level	synonym of **energy source level**	From TNO, 2011
Monopole source level	Synonym for source level	See TNO, 2011, para B3
Source level	The value of 10 $\log_{10}(p_{FF}^2(r)\ r^2/p_{ref}^2\ r_{ref}^2)$, where $p_{FF}(r)$ is the far-field RMS acoustic pressure that would exist at distance r in a specified direction from the source if placed in a hypothetical ideal medium and driven with identical motion of all acoustically active surfaces as in the real medium. The hypothetical medium is a lossless uniform medium of the same characteristic impedance as that at the source location in the true medium, and extending to infinity in all directions.	Based on TNO. 2011, SL_2. There is an alternative definition in the same reference (SL_1) that leads to the same numerical value as SL_2. The quantity $p_{FF}^2(r)\ r^2$/is referred to in Ainslie 2010 and TNO 2011 as the "source factor".
Third (1/3) octave band	A frequency band whose width is one tenth of a decade and whose centre frequency is one of the preferred frequencies listed in IEC 61260:1995 Electro-acoustics – Octave-band and fractional-octave-band filters.	The IEC standard defines a **third octave band** as one tenth of a decade. This choice ensures that round frequencies in powers of ten (not 2), e.g. 10 Hz, 100 Hz, 1 kHz, are included in the set of **third octave band** centre frequencies. The third-octave bands used for analysis are those defined in the international standard IEC 61260:1995 (equivalent to EN 61260:1996). The centre frequencies as described in Commission Decision 2010/477/EU (i.e. 63 and 125 Hz) are nominal centre frequencies and can be interpreted either in decimal or binary. The decimal scale for third-octave bands is preferred to the binary scale.
Trend	general direction in which something is developing or changing. In the context of monitoring, 'trend' refers to year-to-year (or longer) changes in a specific quantity	This report, para 4.2

Term	Proposed definition	Notes
Zero to peak monopole source level	The maximum value of 10 $\log_{10}(p_{FFt}^2(r,t)\ r^2/p_{ref}^2\ r_{ref}^2)$, where $p_{FFt}(r,t)$ is the far-field instantaneous acoustic pressure that would exist at distance r in a specified direction from the source if placed in a hypothetical ideal medium and driven with identical motion of all acoustically active surfaces as in the real medium. The hypothetical medium is a lossless uniform medium of the same characteristic impedance as that at the source location in the true medium, and extending to infinity in all directions.	Based on TNO, 2011

Annex 4: List of acronyms

Acronym	Description
ADC	Analogue to Digital Converter
ADD	Acoustic Deterrent Device
AHD	Acoustic Harassment Device
AIS	Automatic Identification Systems
ANSI	American National Standards Institute
AUV	Autonomous Underwater Vehicle
BSH	Bundesamt für Seeschifffahrt und Hydrographie (DE)
CEFAS	Centre for Environment, Fisheries & Aquaculture Science (UK)
CIRCA	Information Exchange Platform of the European Commission, amongst others for the MSFD
CP	Contracting Parties (of the OSPAR Convention)
dB	Decibel, the most generally used logarithmic scale for describing sound
DECC	Department of Energy and Climate Change (UK)
Defra	Department for Environment, Food and Rural Affairs (UK)
DG ENV	Directorate General on Environment of the European Commission
EC	European Commission
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ENSTA	École Nationale Supérieure de Techniques Avancées (FR)
ESONET	European Seas Observatory NETwork
EU	European Union
GES	Good Environmental Status as defined in the MSFD
HELCOM	Helsinki Commission, Baltic Marine Environment Protection Commission
Hz	Hertz, the SI unit of frequency defined as the number of cycles per second of a periodic phenomenon
ICES	International Council for the Exploration of the Sea
IEC	International Electrotechnical Commission
IMO	International Maritime Organisation
IQOE	International Quiet Ocean Experiment
ISO	International Organization for Standardization
IWC	International Whaling Commission
JNCC	Joint Nature Conservation Committee (UK)
LIDO	Listening to the Deep-Ocean Environment
MARNET	Marine Environmental Monitoring Network in the North- and Baltic Sea
MEDIN	Marine Environmental Data and Information Network (UK)
MOD	Ministry of Defence
MPA	Marine Protected Areas
MS	Member State (of the EU)
MSFD	Marine Strategy Framework Directive
nmi	Nautical mile (1 nmi = 1852 m)
NPL	National Physical Laboratory (UK)
OSPAR	The OSPAR convention (short for “Oslo-Paris” convention) is the current legal instrument guiding international cooperation on the protection of the marine

	environment of the North-East Atlantic.
Pa	Pascal, the SI derived unit of pressure (one newton per square metre)
PCAD	Population Consequences of Acoustic Disturbance (a model)
POGO	Partnership for Observation of the Global Oceans
PTS	Permanent hearing Threshold Shift
RMS	Root mean square
ROV	Remotely-Operated Vehicle
RWS	Rijkswaterstaat (NL)
SCOR	Scientific Committee on Oceanic Research
SEA	Strategic Environmental Assessment
SEL	Sound Exposure Level
SHOM	Service hydrographique et océanographique de la marine (French Hydrographic Office)
SI	The International System of Units
SPL	Sound Pressure Level
TG11	Task Group of Descriptor 11 (Noise/Energy) of the MSFD. The TG11 report is referred to as Tasker *et al*. (2010).
TNO	Netherlands Organization for Applied Scientific Research (NL)
TNT	Trinitrotoluene, $C_6H_2(NO_2)_3CH_3$
ToR	Terms of Reference
TSG Noise	EU Technical Subgroup on Noise
TTS	Temporary hearing Threshold Shift
USN	United States Navy
WG GES	EU Working Group Good Environmental Status

Annex 5: Considerations on the possible use of a theoretical framework

In order to identify which effects can be regarded as the most relevant effects, we can use a framework for assessing the temporal and spatial scale of noise related effects in the marine environment. The TG11-report offers three possible frameworks.

1) The concept of zones of noise influence (Richardson *et al*. 1995),
2) The Population Consequences of Acoustic Disturbance Model (NRC 2005), and
3) The application of risk assessment frameworks in noise-effect studies (MMC 2007; Boyd *et al*. 2008).

Comparing the available frameworks.

1) The concept of zones of noise influence.

Richardson defines several theoretical overlapping zones of noise influence (from a single noise source), depending on the distance between the source and the receiver. The zone of audibility is the largest and the zone leading to the death of an individual receiver, the smallest. This model has been used very often in impact assessments where the zones of noise influence are determined based on sound propagation modelling or sound pressure level measurements on the one hand, and information on the hearing capabilities of the species in question on the other. It should be noted that this model gives only a very rough estimate of the zones of influence, as sound in the seas is always three-dimensional. It can, however, provide a starting point in investigating the relationship between spatial scale and temporal scale of effects, and it was in effect used in the OSPAR report for this purpose (OSPAR 2009). It is probably not the best choice to identify the most relevant effect as needed for the indicator, due to the limited reliability of the estimates of the zones of influence and because of the many variables involved.

2) Population Consequence of Acoustic Disturbance Model

The links between the receiving of a sound by an individual organism and any changes in the biology of that organism can be complex, especially for any population level effect. In theory, a temporary change in an individual's behaviour could be linked to long-term population level consequences. These links are addressed by the Population Consequence of Acoustic Disturbance Model (PCAD). The model, developed for marine mammals but in theory applicable to other parts of the marine environment as well, involves different steps from sound source characteristics through behavioural change, life functions affected, and effects on vital rates to population consequences. As can be seen in Figure 2, most of the transfer functions and variables of the PCAD model are currently unknown. Challenges to fill in gaps can come in many ways, due to uncertainties in population estimates for several species / regions, difficulties in weighting noise against and accumulating with other stressors, difficulties in quantifying noise impacts etc. It is evident that potential impacts of sound have to be placed in a wider context, addressing the consequences of acoustic disturbance on populations in conjunction with other factors. However, because of the uncertainties the PCAD model can not be used for determining relevant and less relevant effects.

3) Risk assessment frameworks

The application of risk assessment frameworks, originally developed for examining the impacts of chemicals, provide a tool for a more systematic approach and has been conceptualised for marine mammal noise impact studies by scientific bodies in Europe and the U.S. (MMC 2007;Boyd *et al*. 2008).

The risk-based assessment follows a stepwise approach:

1) Hazard identification: what are the actual and potential threats from each activity e.g. sound sources.

2) Exposure assessment (determine exposure to hazards): marine mammal numbers and distribution (results of baseline); characteristics of hazard and overlap between mammals and hazard (spectral, temporal, and spatial). This deals with scales of potential impacts by looking at received sound pressure levels at various ranges in relation to animal density to identify the number of individuals potentially affected. The investigation of the overlap between sources and exposed organisms is. We consider that the scale of effect is dependent on d/e relation and propagation.
3) Exposure response assessment (determine range of possible responses): marine mammal sensitivities at the species level (and higher levels if possible) establishing dose-response relationships. This concerns the responses as such and will lead to conclusions on the temporal scale of noise related effects.
4) Risk characterisation: assessment of the overall risk of the impact including establishment of likelihoods and uncertainties.
5) Risk management: mitigation (for more details see Boyd *et al*. 2008).

Annex 6: UK experience in establishing a baseline

The UK examined two sources of information on activities that generate pulses relevant to this indicator that occurred in its waters over the period 2008-2010, namely seismic surveys and wind farm installations. Although these two activities do not comprise all of the known sources of relevant pulses, they are probably constitutes the majority of sources to be treated by the descriptor.

Method for analysing UK seismic survey information

The UK regulator, the Department of Energy and Climate Change (DECC), compiled information on the seismic surveys that were notified during the years 2008- 2010. The information aimed to include

- the dates and number of days over which the survey occurred
- the UK licensing blocks covered by the survey

All seismic surveys are required to notify DECC prior to starting the survey and to report afterwards what actually happened (the two are rarely the same due to periods of poor weather, equipment malfunction etc). The data provided start, end dates and duration applied for, but some had incomplete reports that did not specify the total number of days surveyed. This resulted in incomplete data sets for the actual duration (number of pulse-days) of the surveys undertaken in these instances.

If data were provided in a report, the difference between the start and end dates was used to calculate the survey duration and the total number of seismic 'pulse-days'. If data were not provided in the report, a conversion factor was applied to provide the number of pulse-days for each application. The conversion factor was calculated as a ratio using information from surveys that had information both on number of days that were applied for and on number of days that the survey actually took place on. (The number of days applied for is almost always larger than the number of days when survey actually took place). The mean average of this ratio for all surveys in a given year was applied as the conversion factor to data in that year where the actual number of survey days was not reported. The number of survey days applied for was multiplied by the conversion factor to give an inferred best estimate.

If a survey spanned more than one block, the number of pulse-days of survey was divided by the number of blocks applied for, to give the number of pulse-block-days for that survey. This will underestimate, possibly considerably, the total number of pulse-block-days, as most surveys will occur in more than one block each day. There is insufficient information to enable an estimate of the average number of blocks surveyed in any one day to be used as a conversion factor.

In some cases, only the quadrants (units of 30 blocks, 1 degree latitude x 1 degree longitude) were stipulated in the application and precise survey blocks were not given. In these cases, the full number of seismic pulse-block-days applied for were assumed to have been undertaken in each block within the quadrant. This will over-estimate the total number of pulse-block-days. There was insufficient information on the average number of blocks actually surveyed within each of these quadrant-based surveys to be used as a conversion factor

It was assumed that all seismic surveys would emit pulses at a greater intensity than the source threshold in the indicator. Nevertheless, for interest (and because the information was usually available), surveys were categorised as 2D, 3D or 4D. The former tend to be relatively wide area surveys (with greater geological information deriving from 3D than from 2D) while 4D surveys tend to be relatively localised, but are repeated much more frequently (4D surveys are used for management of hydrocarbon extraction from producing fields). If no information to categorise a survey it was assumed to be 2D as these dominated application requests between 2008-2010.

The whole-year datasets were also split up using the ICES divisions to give a regional representation of the level of seismic surveys undertaken.

Method for analysing UK offshore windfarm installation information

Over the period 2008-2010, all UK offshore wind farms were installed by pile driving. Hull *et al*. (2011) obtained the information from developers/owners of offshore windfarms for which construction was completed during or after 2007 or which were currently under construction.

Information on the location of offshore windfarms piles and the dates on which the piles were inserted was obtained from the developers. Three offshore windfarms had not yet started piling operations and one had only just started piling operations. These four sites were therefore excluded from the analysis.

The piling dates/times provided by developers variously referred to the start or finish times of piling activity and it has not been possible to convert them to a common basis. However, this does not introduce inaccuracy into the analysis as most pile insertions require only 60-90 minutes to complete and therefore the vast majority of pile insertions will have been started and completed on the same day.

All piling records were assigned to a UK hydrocarbon-licensing block. One development occurred in an area inshore of the licensing blocks. The footprint of the development occupies an area less than 1 block and for the purposes of the analysis it was therefore assumed that only one block was affected.

Results from UK seismic surveys 2008-2010

At the crudest scale (whole UK waters) the number of these block pulse days has stayed relatively constant over the time (19783 total pulse-block-days in 2008, 16813 in 2009 and 17437 in 2010). It is possible to amalgamate the information by other geographic divisions to illustrate heterogeneity or allow target setting/monitoring by smaller geographic areas. Table A illustrates the data organised by ICES sub-division.

Table A. Total number of seismic survey block pulse days in UK waters for 2010, organised by ICES sub-division. The data available for this table were not adapted for the purpose and a number of assumptions were made.

	ICES Sub-Division					
	IIa	**IVa**	**IVb**	**IVc**	**VIa**	**VIIa**
Total seismic pulse days in 2010	2933	6855	4551	23	1553	40
Number of UK blocks in ICES division	151	779	517	195	801	186
Average pulse days per year per block	19.4	8.8	8.8	0.12	1.9	0.21

Results from UK offshore windfarm installation 2008-2010

The locations of those offshore windfarms for which piling records were obtained and analysed are presented in relation to ICES sub-division (Table B).

The analysis for 2008-2010 has involved 9 offshore windfarms and some 595 piles. All offshore windfarms used monopile foundations apart from one, which used steel jackets, requiring the insertion of four piles for each turbine foundation. The monthly pattern of piling was not even, and was not focussed on any particular time of year during these years (Figure A). The total number of pulse-block-days from pile driving in each off the years 2008, 2009 and 2010 was 130, 224 and 321 respectively.

Table B. UK offshore wind farm piles and insertion dates (2008-2010) by ICES sub-region

	OWF	Insertion period	Piles inserted
ICES IVc	Gunfleet Sands I	Oct 2008 - Oct 2009	30
	Gunfleet Sands II	Oct 2008 - Oct 2009	20
	Thanet	Apr 2009 - Jan 2010	100
	Inner Gabbard	Jan 2010 - Aug 2010	54
	Sheringham Shoal	Jun 2010 - Ongoing	66
ICES VI	Robin Rigg	Dec 2007 - Feb 2009	60
	Rhyl Flats	Apr 2008 - Aug 2008	25
	Walney I	Apr 2010 - Aug 2010	51
	Ormonde	May 2010 - Sep 2010	120

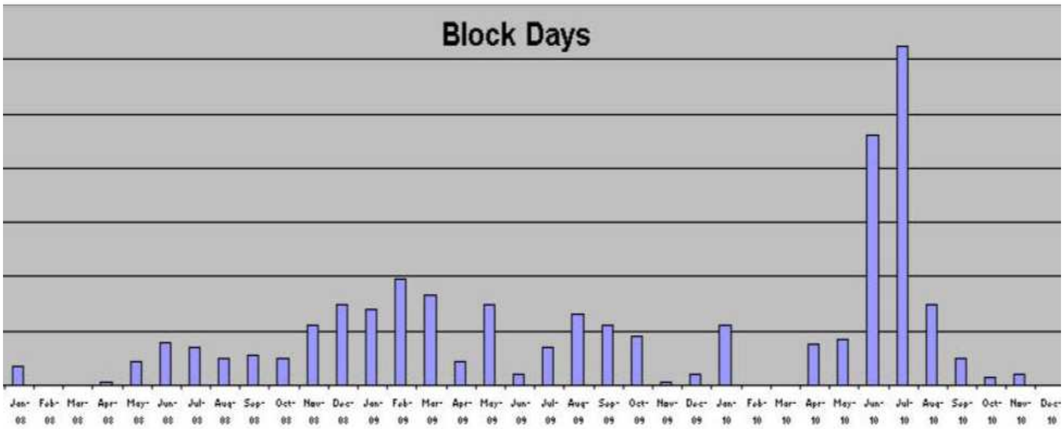
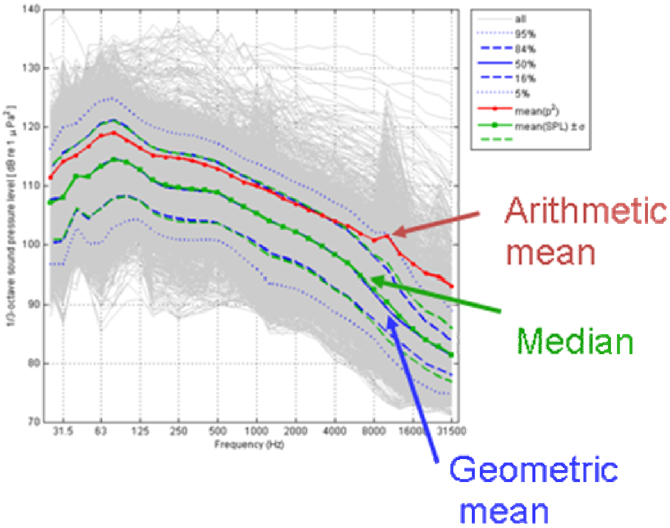


Figure A. Monthly number of pile installations for offshore windfarms in UK waters, 2008-2010. Each horizontal line represents 20 days. Data for ICES IVc and VI combined here, but can be separated.

Annex 7: Analysis of methods to determine the average sound level

Example: 2008 measurements close to the Port of Rotterdam (Ainslie *et al.* 2011b)

- Median
    - Depends on sample averaging time (= 6 s)
- Geometric mean (average in dB)
    - Close to median
- Arithmetic mean (power average)
    - 5 to 10 dB higher
    - Sometimes needed
    - Rarely reported
- ~ log-normal distribution



Solution proposed:

Make use of the arithmetic mean, i.e. averaged over the square pressure (not over levels in dB)

Annex 8: Further research needs

Research Issue	General description	Necessary critical information
Acoustic measurements and relevant sound sources	Detailed measurements on source levels, frequency content and sound field radii around intense/chronic sound sources	Exhaustive and calibrated measurements of the properties of man-made acoustic sources, including propagation depending on frequency and the received characteristics in different environments.
Measurement of ambient noise	Systematic measurement of sub-aquatic marine environment noise necessary to quantify how human activity affects them in the acoustic medium. Real time monitoring for decision making in the event of negative impact.	Exhaustive and calibrated measurements of ambient noise, including spectral, temporal and directional aspects in different ocean environments.
Risk assessment studies	Work on the assessment of risk in accumulated effects and synergies from noise and other exposures to individuals and populations.	Research on the effects of noise in ecological and dynamic processes in populations together with accumulated and synergetic effects from noise and other environmental stress elements. In order to obtain in-depth information of impacts on populations, long-term systematic observations are necessary to avoid adding unnecessary noise to the environment.
Masking effects of sound exposure on the hearing of marine organisms	A continued and analytical effort is needed on the effects of sound exposure on the hearing of marine organisms as with the understanding of their basic acoustic capacities.	Auditory thresholds of masking for chronic and acute stimuli in species and individuals, Consider directional effects: data compared in the first appearance of TTS and growth in a greater number of species and individuals for anthropogenic pulsed and non-pulsed sources; recuperative functions after one and between repeated exposures.
Definition of exclusion zones	More research is needed for the determination of safe areas and their vigilance (acoustic and visual monitoring), such as geographic and seasonal restrictions on developing acoustic activity.	To avoid sound exposure in a great number of cetaceans and other marine organisms, studies must be carried out in the following areas to: - identify “hot spots” and “cold spots” or ocean deserts for marine life where it will be more adequate for the performance of activities which produce high sound levels. - define safe zones around sites where anthropogenic noise generating activities are being carried out. This can be conducted through the passive acoustic monitoring of the activity, and an alert service that would provide information on the presence of noise-sensitive species.
Global Management of noisy activities in MPAs	MPAs should be taken as pilot areas to manage human activities based on their noise levels	In particular areas, like MPAs, models based on oceanographic conditions, bathymetry and in situ noise monitoring must be developed to efficiently manage the noise budget over time and decide on the introduction of new activities.