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# Monitoring Guidance for Underwater Noise in European Seas

A guidance document within the Common Implementation Strategy for the Marine Strategy Framework Directive.

## OSPAR Agreement 2014-08

The Environmental Impact of Human Activities Committee (EIHA) 2014 agreed to adopt the EU technical sub group monitoring guidance for underwater noise in European seas as the OSPAR guidelines for undertaking coordinated monitoring of noise.

EIHA 2014 adopted a reporting format (Agreement 2014-10) and associated explanatory notes for OSPAR impulsive noise.



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# Monitoring Guidance for Underwater Noise in European Seas

## Part I: Executive Summary

*A guidance document within the  
Common Implementation  
Strategy for the Marine  
Strategy Framework Directive*

MSFD Technical Subgroup on  
Underwater Noise

2014



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## SUMMARY

The Marine Strategy Framework Directive (MSFD) requires European Member States (MS) to develop strategies for their marine waters that should lead to programmes of measures that achieve or maintain Good Environmental Status (GES) in European Seas. As an essential step in reaching good environmental status, MS should establish monitoring programmes enabling the state of the marine waters concerned to be assessed on a regular basis. Criteria and methodological standards on GES of marine waters were published in 2010 (Commission Decision 2010/477/EU). Two indicators were described for Descriptor 11 (Noise/Energy): 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 Subgroup (TSG) for further development of Descriptor 11 Noise/Energy. TSG (Underwater) Noise in 2011 focused on clarifying the purpose, use and limitation of the indicators and described methodology that would be unambiguous, effective and practicable; the first report [Van der Graaf et al., 2012]<sup>1</sup> was delivered in February 2012. Significant progress was made in the interpretation and practical implementation of the two indicators, and most ambiguities were solved.

In December 2011, EU Marine Directors requested the continuation of TSG Noise, and the group was tasked with recommending how MS might best make the indicators of the Commission Decision operational. TSG Noise was asked first to provide monitoring guidance that could be used by MS in establishing monitoring schemes for underwater noise in their marine waters. Further work includes providing suggestions for (future) target setting; for addressing the biological impacts of anthropogenic underwater noise and to evaluate new information on the effects of sound on marine biota with a view to considering indicators of noise effects.

The present document is **Part I** of the **Monitoring Guidance for Underwater Noise in European Seas** and provides MS with the information needed to commence the monitoring required to implement this aspect of MSFD. TSG Noise has focused on ambiguities, uncertainties and other shortcomings that may hinder monitoring initiatives and has provided solutions, and describes methodology for monitoring both impulsive and ambient noise in such a way that information needed for management and policy can be collected in a cost-effective way. TSG Noise has no doubt that further issues will arise once monitoring starts, but hopes the principles laid out in this guidance will help resolve these.

The Monitoring Guidance for Underwater Noise is structured, as follows:

- **Part I: Executive Summary & Recommendations,**
- Part II: Monitoring Guidance Specifications, and
- Part III: Background Information and Annexes.

Part I of the Monitoring Guidance is the executive summary for policy and decision makers responsible for the adoption and implementation of MSFD at national level. It provides the key conclusions and recommendations presented in Part II that support the practical guidance for MS and will, enable assessment of the current level of underwater noise.

Part II, is the main report of the Monitoring Guidance. It provides specifications for the monitoring of underwater noise, with dedicated sections on impulsive noise (Criterion 11.1 of the Commission Decision) and ambient noise (Criterion 11.2 of the Commission Decision)

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<sup>1</sup> The 1<sup>st</sup> TSG Noise Report (27 February 2012) available online:  
[http://ec.europa.eu/environment/marine/pdf/MSFD\\_reportTSG\\_Noise.pdf](http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf)

designed for those responsible for implementation of noise monitoring/modelling, and noise registration.

Part III, the background information and annexes, is not part of the guidance, but is added for additional information, examples and references that support the Monitoring Guidance specifications.

## 1. INTRODUCTION TO 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. Among these, the most widespread and pervasive is underwater sound. It is likely that the amount of underwater sound, and therefore 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 these changes. The numbers of anthropogenic electromagnetic fields are increasing due to the increasing number of power cables crossing our seas but these emissions are relatively localised to the cables. Light and heat emissions are also relatively localised, but may have significant local effects (Tasker *et al.* 2010).

Sound energy input can occur on many scales in both space and time. Anthropogenic sounds may be of short duration (*i.e.* impulsive) or be long lasting (*i.e.* continuous); impulsive sounds may however be repeated at intervals (duty cycle) and such repetition may become diffuse 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 which 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. injury, death). These adverse effects can be widespread (as opposed to localised for other forms of energy) and, following the recommendations of Tasker *et al.* (2010), in September 2010 the European Commission identified the main orientations for monitoring of underwater noise that should be used to describe Good Environmental Status (GES).

Two indicators were published for Descriptor 11 (Noise/Energy) of the MSFD 2008/56/EC in the EC Decision 2010/477/EU on criteria and methodological standards on GES of marine waters. 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 EC Decision, the Marine Directors agreed to establish a technical sub-group (TSG) for further development of Descriptor 11 Noise/Energy. This report compiles the recommendations of TSG Noise. Text box 1 shows the extract of the EC Decision specifically for the indicators of Descriptor 11.

**Text Box 1: Extract of the indicators for Descriptor 11 (Noise/Energy) from EC 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 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 (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 1 $\mu$ Pa 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).

This report provides guidance to Member States for establishing monitoring programmes for these indicators of underwater sound. In this executive summary, only the *key* conclusions and recommendations are provided.

The TSG Noise conclusions and recommendations are further developed and specified in Parts II (Technical Specifications) and III (background information, examples and annexes).



## 2. TSG NOISE KEY CONCLUSIONS AND RECOMMENDATIONS

### 2.1 Monitoring Guidance for Impulsive Noise

This chapter contains the conclusions and recommendations provided by the TSG Noise for the establishment of monitoring programmes of **impulsive noise** as covered by the EU MSFD indicator “11.1. Distribution in time and place of loud, low and mid frequency impulsive sounds”.

A basic principle of the MSFD is that it addresses the ecosystem rather than individual animals or species (consideration 5: the development and implementation of the thematic strategy should be aimed at the conservation of the marine ecosystems). This indicator addresses the cumulative impact of activities, rather than that of individual projects or programme (those are addressed by other EU legislation); effects of local/singular activities are not covered. This indicator alone is not intended, nor is it sufficient, to manage singular events, but Environmental Impact Assessments (EIA) can be used to assess, and where necessary, to limit the environmental impacts of individual projects.

*Indicator 11.1.1 on low and midfrequency impulsive sounds:*

*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 source level or suitable proxy 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).*

TSG Noise suggested that “considerable” displacement is the most relevant effect of loud low and mid-frequency sounds that can practicably be measured - this may lead to population effects and thus should be addressed by Indicator 11.1.1. “Considerable” displacement means displacement of a significant proportion of individuals for a relevant time period and at a relevant spatial scale. The indicator addresses the cumulative impact of sound generating activities and possible associated displacement, where effects may occur at the ecosystem level.

The initial purpose of monitoring impulsive noise is to quantify the pressure on the environment, by making available an overview of all loud impulsive low and mid-frequency sound sources, throughout the year, in regional seas. This will enable MS to get a reasonably complete overview of the occurrence of all the activities that produce the relevant sounds that place pressure on the environment, which has not previously been achieved. It will also make it easier to assess cumulative effects of the pressure on the environment (see First report of TSG Noise, Feb 2012).

TSG Noise recommends monitoring of indicator 11.1.1 by **setting up a register of the occurrence of these impulsive sounds**. This is the first step to establish the current level and trend in these impulsive sounds.

Airguns, pile-driving, explosives, and sonar working at relevant frequencies and some acoustic deterrent devices are the **most important sound-sources that should be considered for inclusion in the register**. Additional sources that could also be of concern include boomers, sparkers and scientific echo sounders. TSG Noise recommends thresholds for uptake in the register. Thresholds were derived that will ensure that *all* sources that have a *potential* for significant population level effect will be included in the register. However, the use of these (relatively low) thresholds will result in sources with a relatively low potential for significant

impact also being registered. TSG Noise concluded that there is a need for more detail in the register than just the day and location; of this additional information, the source level is the most important.

The **information required** to derive pulse-block days (the number of days that a certain threshold (pulse) is exceeded in an area (block)), are:

- Position data (geographic position (lat/long), licensing block/area)
- Date of operation
- Source properties:
  - Essential (minimum)
    - Source level or proxy;

Additional data will be beneficial for improved assessment - where available the following may also be recorded:

- Source spectra;
- Duty cycle;
- Duration of transmissions (and actual time/time period);
- Directivity;
- Source depth;
- Platform speed

It is possible that many operators (e.g. navies using sonar) may have concerns about releasing sensitive information. Where detailed information of source properties is requested it is proposed that source level may be recorded in bins (of e.g. 10 dB) rather than using a precise figure.

The **main aim of the registry** is to provide an overview of all loud sounds. If the registry leaves out certain sound sources it would not fulfil the aim of addressing cumulative effects of impulsive noise; it is therefore recommended that information on all sources should be included [see Van der Graaf *et al.*, 2012]. TSG Noise therefore suggest that **data on explosives and military activities** (of which the sole purpose is defence or national security) **should also be included in the register**, but notes that this should be on a voluntary basis as this is a national policy issue.

TSG recommends that **a common register be set up at least on a Regional Sea level**, the format of which must ensure future compatibility. This cannot be conclusively decided until the register location and management are decided, but there are some factors that could be agreed upon, such as:

- ✓ Use of a common language (English)
- ✓ Use of a common format for date in accordance with the appropriate standard (ISO 8601) (YYYY-MM-DD or YYYYMMDD)
- ✓ Use of a common format for position (latitude and longitude, decimal degrees)
- ✓ Use of a common map projection (unprojected data – WGS84)
- ✓ Use of a common template (i.e. setting out the order in which information is recorded)

For some of the data (e.g. seismic survey data) the use of a grid (based on standard licensing blocks) may be practicable to collect (part of) the data on impulsive noise. Member States may choose to use such a grid to organise data (for instance, use the above-mentioned blocks to store data instead of the actual positions of a piling activity). Member States may also choose to use such a grid for other purposes e.g. presenting data, assessment purposes and for future management action.

In such cases, the actual choice of grid definition, and the size of the grid cells, is a choice that should be made by Member States and this can be based on practical considerations, e.g. where

data are registered in standard hydrocarbon licensing blocks. For easier interpretation of results in a common register for a regional sea, TSG Noise would recommend one standard grid size to be used by Member States.

If the grid chosen by Member States is to be used for assessment purposes, it should be noted that it may not be of the same spatial scale as the area actually affected by the noise source. The number of days (or proportion/percentage of a longer period) over which activities occur should not necessarily be interpreted as a direct measure of habitat loss (holes in distribution). A correction factor could be applied when comparing results that are generated using different grid sizes, or if the grid sizes are not appropriate for definitions of targets. There may also be issues for grid cells in coastal areas or at boundaries between Member States. For these blocks some additional considerations may apply.

Minimum noise thresholds have been defined for low and mid-frequency sources as a basis for including sources in the register. For background and explanation of these values see Part III of the Monitoring Guidance (chapter 2.1)

For impact pile-drivers no minimum threshold should be used and all pile-driving activities should be registered.

For sonar, airguns, acoustic deterrents and explosives, minimum thresholds should be used for uptake in the registers. The generic source level (SL) threshold for inclusion in the register for non-impulsive sources is 176 dB re 1  $\mu\text{Pa m}$ , whereas the threshold for inclusion of impulsive sources is an energy source level ( $SL_E$ ) of 186 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$ . For airguns and explosives it is more convenient to convert these to proxies of zero to peak source level ( $SL_{z-p}$ ) and equivalent TNT charge mass ( $m_{\text{TNTeq}}$ ), respectively.

The recommended thresholds for these source levels and proxies of short duration sound sources are listed below.

- |                                     |  |
|-------------------------------------|--|
| • Explosive:                        | $m_{\text{TNTeq}} > 8 \text{ g}$                                 |
| • Airgun:                           | $SL_{z-p} > 209 \text{ dB re } 1 \mu\text{Pa m}$                 |
| • Other pulse sound source          | $SL_E > 186 \text{ dB re } 1 \mu\text{Pa}^2 \text{m}^2 \text{s}$ |
| • Low-mid frequency sonar:          | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$                       |
| • Low-mid freq. acoustic deterrent: | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$                       |
| • Other nonpulse sound source:      | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$                       |

Where levels are reported in bins instead of a precise level, it is proposed that they report source level as follows:

**Sonar or acoustic deterrents (source level, rounded to nearest decibel):**

- Very low: 176-200 dB re 1  $\mu\text{Pa m}$
- Low: 201-210 dB re 1  $\mu\text{Pa m}$
- Medium: 211-220 dB re 1  $\mu\text{Pa m}$
- High: above 220 dB re 1  $\mu\text{Pa m}$

**Generic explicitly impulsive source (energy source level, rounded to nearest decibel):**

- Very low: 186-210 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$
- Low: 211-220 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$
- Medium: 221-230 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$
- High: above 230 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$

**Airgun arrays (zero to peak source level, rounded to nearest decibel):**

- Very low: 209-233 dB re 1  $\mu$ Pa m
- Low: 234-243 dB re 1  $\mu$ Pa m
- Medium: 244-253 dB re 1  $\mu$ Pa m
- High: above 253 dB re 1  $\mu$ Pa m

**Explosions (equivalent TNT charge mass, rounded to nearest 10 g if less than 10 kg and to nearest 1 kg otherwise)**

- Very low: 8 g to 210 g
- Low: 220 g to 2.1 kg
- medium: 2.11-21 kg
- high: 22-210 kg
- Very high: above 210 kg

**Impact pile driver (hammer energy, rounded to nearest 10 kJ)**

- Very low: less than 280 kJ
- Low: 290 kJ-2.80 MJ
- Medium: 2.81-28 MJ
- High: above 28 MJ

The register can be used to estimate **the spatial and temporal impact on the environment** (the total period and total habitat loss by impulsive noise sources) and for determining the **baseline level**.

The register will describe the **pressure** on the environment the spatial and temporal distribution of impulsive noise sources. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists. More specifically, this indicator is designed to provide information describing temporal and spatial distribution of impulsive noise sources, through the year and throughout regional seas, to enable assessment of possible cumulative impacts of displacement on marine species at the population level. Current data on bio-acoustic impacts are mostly limited to short-term individual responses. Cumulative exposures from multiple noise sources over large geographic scales and long durations can be modelled, but little is known about the effects of displacement caused by cumulative acoustic exposure. The data gathered in the register will enable MS to estimate the size of the area affected by anthropogenic impulsive noise sources. Using information on response thresholds in received levels for particular species, the area of displacement can be estimated. **Further steps are needed to assess** how displacement affects a species at the **population level**. This requires **considerable research**, even for well-studied species, and results are likely to vary between species.

Once operational, the register will provide Member States a quantified assessment of the spatial and temporal distribution of impulsive noise sources, throughout the year, in regional seas; his assessment can be **used to help decide policy targets** and to **establish the baseline** for the current situation. Once a baseline and targets have been set, the register can be used for **management purposes** (e.g. regulating planning and licensing activities) and to assist in marine spatial planning, incorporating displacement mitigation guidelines and **reducing the potential for cumulative impacts**.

## 2.2 Monitoring Guidance for Ambient Noise

This chapter provides a guide for **the monitoring of ambient noise** as covered by the EU MSFD indicator 11.2.1.

To make indicator 11.2.1. operational and to comply with the Commission Decision of 2010 (CD): to monitor trends, advice on scope and optimal approach are provided.

*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  $\mu$ Pa, either measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations [Van der Graaf, 2012].*

TSG Noise concludes that the **combined use of measurements and models** (and possibly sound maps) is the best way for Member States to ascertain levels and trends of ambient noise in the relevant frequency bands. Member States should be careful to balance modelling with appropriate measurements.

The use of modelling for indicators and noise statistics, and possibly the creation of noise maps, ensures that trend estimation is more reliable and cost-effective, for the following reasons:

- i. Use of models reduces the time required to establish a trend, with a fixed number of measurement stations (the expected trend in shipping noise, based on observations in deep water, is of the order of 0.1 dB/year; and therefore it takes many years, possibly decades, to reveal such small trends without the help of *spatial averaging*)
- ii. Use of models reduces the number of stations required to establish a trend over a fixed amount of time (similar reasoning), therefore reducing the cost of monitoring
- iii. Modelling helps with the choice of monitoring positions and equipment (selecting locations where the shipping noise is dominant as opposed to explosions or seismic surveys being dominant)

The use of models provides MS with an overview of actual levels and their distribution across the sea area, thereby enabling identification of a departure from GES. In addition, there are advantages of using modelling that could contribute to a greater understanding of potential impacts of noise,

The use of mapping has some history and in implementing the MSFD and one can make use of previous experience. Relevant EU experience and regulation is summarised in part II providing some useful background for the MSFD.

This report provides concrete advice on **specifications for noise monitoring systems**. TSG Noise notes that there are no international standards for monitoring underwater ambient noise, for modelling and for data storage. TSG Noise concludes that such standards are needed. **TSG Noise therefore recommends that international standards be developed for the measurement, modelling and data storage of ambient noise** with application to underwater noise monitoring, including the measurement of radiated sound from important sources such as airgun arrays and underwater explosions (standards for the measurement of radiated sound from ships and impact pile driving are already under development by ISO).

TSG Noise advises **Member States within a sub region to work together in setting up n ambient noise monitoring systems**. No precise locations for deploying equipment necessary to monitor relevant frequency bands of ambient noise have yet been defined. However, TSG

Noise is providing a set of guidelines for **monitoring strategy** and guidance **for reporting results**.

It is the responsibility of the MS to define exact locations for the monitoring of Indicator 11.2.1. The indicator is a pressure-indicator that should be used to document trends and not to provide a complete coverage of all noise for the area of interest. If a trend is detected in an area, it should also provide evidence about the trend in other areas (for example an MPA).

The prime objective for the monitoring programme is to establish the trend. However, since the benefit of using models is acknowledged, the monitoring programme should pursue two linked objectives with separate specific monitoring strategies:

- **Category A Monitoring** - to establish information on the ambient noise in a location and to ground truth noise prediction,
- **Category B Monitoring**- to reduce uncertainty on source levels to be used as the input for modelling.

Following these strategies, TSG Noise recommends an **initial set of guidelines for placement of measurement devices**:

- 1- Where there are few measuring stations per basin, priority should be given to monitoring in order to ground truth predictions (category A), since this monitoring is less sensitive to the influence of individual ships that might bias the averaged sound pressure levels. Monitoring may be more cost effective if existing stations are used for monitoring other oceanographic features;
- 2- Member States should make sure that they have access to data on the noise characteristics of individual ships
- 3- In deep water, monitoring devices to ground truth predictions (category A) should be placed in areas of low shipping density. The range at which elevated noise levels may occur is greater in deep water as low frequency sound can propagate long distances;
- 4- Consider local topography and bathymetry effects e.g. where there are pronounced coastal landscapes or islands/archipelagos it may be appropriate to place hydrophones on both sides of the feature;
- 5- In waters subject to trawling, use locations that are protected from fishing activities or locations where trawling is avoided due to bottom features (e.g. underwater structures/wrecks) and/or to use trawl safe protection;
- 6- As far as possible avoid locations close to other sound producing sources that might interfere with measurements e.g. oil and gas exploration or offshore construction activities. Areas of particularly high tidal currents may also affect the quality of the measurement;
- 7- In all underwater noise monitoring, the location should be chosen taking into account site-specific properties such as tide, sediment and currents; it is important that the rig is silent and rig design should take account site-specific considerations.
- 8- Calibrate sensors at the same pressure as encountered at the planned deployment depths (for clarification see part III chapter 2.10)

The advantages and disadvantages of different averaging methods (arithmetic mean, geometric mean, median and mode) were reviewed, and TSG Noise **recommends that Member States adopt the arithmetic mean** to establish **average ambient noise levels**. The value found will be dominated by the noisiest contribution. Therefore, monitoring in the established high pressure areas (such as commercial traffic lanes) will be emphasised by this contribution. Any other contribution, especially contribution at the regional scale will be de-emphasised. As a consequence, significant pressure fluctuation at a region scale will be disregarded by only listening near traffic lanes.



In order to establish the statistical significance of the trend, additional statistical information about the distribution is necessary. Until better advice becomes available, it is recommended that the **complete distribution be retained in the form of sound pressure levels as a function of time, along with a specified averaging time**

**Monitoring indicator 11.2.1** will enable MS to quantify the environmental **pressure** (expressed as ambient noise level) as well as trends in ambient noise levels within the two frequency bands. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists. Since there **is very little information available on the effects of increased ambient noise level, TSG Noise cannot give concrete advice on interpretation of results at this stage.**

In addition to the advice needed to develop and deploy the systems needed to monitor the indicator, TSG Noise concluded that *trends* only will not be sufficient to describe GES. To describe GES *levels*, based on a wider overview of the area, a combination of modelling / measurements and possible mapping will be needed. Next to that, much greater **understanding of the relationship between the environmental pressure caused by ambient noise and the state of the ecosystem is needed before GES can be understood.**

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Abstract

This document has been prepared by the Technical Subgroup on Underwater Noise and other forms of Energy (TSG Noise), established in 2010 by the Marine Directors, i.e. the representatives of directorates or units in European Union Member States, Accessing Countries, Candidate Countries and EFTA Member States dealing with or responsible for marine issues. In December 2011, the Marine Directors requested the TSG Noise to provide monitoring guidance that could be used by Member States in establishing monitoring schemes to meet the needs of the Marine Strategy Framework Directive indicators for underwater noise in their marine waters. This document presents the key conclusions and recommendations that support the implementation of the practical guidance to commence the monitoring required for underwater noise.



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JRC SCIENTIFIC AND POLICY REPORTS

# Monitoring Guidance for Underwater Noise in European Seas

## Part II: Monitoring Guidance Specifications

*A guidance document within the  
Common Implementation  
Strategy for the Marine  
Strategy Framework Directive*

MSFD Technical Subgroup on  
Underwater Noise

2014



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## FOREWORD

The Marine Directors of the European Union (EU), Accessing Countries, Candidate Countries and EFTA Countries have jointly developed a common strategy for supporting the implementation of the Directive 2008/56/EC, “the Marine Strategy Framework Directive” (MSFD). The main aim of this strategy is to allow a coherent and harmonious implementation of the Directive. Focus is on methodological questions related to a common understanding of the technical and scientific implications of the Marine Strategy Framework Directive. In particular, one of the objectives of the strategy is the development of non-legally binding and practical documents, such as this recommendation, on various technical issues of the Directive. These documents are targeted to those experts who are directly or indirectly implementing the MSFD in the marine regions.

This document has been prepared by the Technical Sub-Group on Underwater Noise and other forms of Energy (TSG Noise), established in 2010 by the Marine Directors. In December 2011, EU Marine Directors requested the TSG Noise to provide monitoring guidance that could be used by MS in establishing monitoring schemes to meet the needs of the MSFD indicators for underwater noise in their marine waters.

The Marine Strategy Coordination Group has agreed (in accordance with Article 6 of its Rules of Procedures) to publish this document as technical guidance developed in the MSFD Common Implementation Strategy. The participants of the Marine Strategy Coordination Group concluded:

*“We would like to thank the experts who have prepared this high quality document. We strongly believe that this and other documents developed under the Common Implementation Strategy will play a key role in the process of implementing the Marine Strategy Framework Directive. This document is a living document that will need continuous input and improvements as application and experience build up in all countries of the European Union and beyond. We agree, however, that this document will be made publicly available in its current form in order to present it to a wider public as a basis for carrying forward on-going implementation work.”*

The Marine Strategy Coordination Group will assess and decide upon the necessity for reviewing this document in the light of scientific and technical progress and experiences gained in implementing the Marine Strategy Framework Directive.

### **Disclaimer:**

*This document has been developed through a collaborative programme involving the European Commission, all EU Member States, the Accession Countries, and Norway, international organisations, including the Regional Sea Conventions and other stakeholders and Non-Governmental Organisations. The document should be regarded as presenting an informal consensus position on best practice agreed by all partners. However, the document does not necessarily represent the official, formal position of any of the partners. Hence, the views expressed in the document do not necessarily represent the views of the European Commission.*

## SUMMARY

The Marine Strategy Framework Directive (MSFD) requires European Member States (MS) to develop strategies for their marine waters that should lead to programmes of measures that achieve or maintain Good Environmental Status (GES) in European Seas. As an essential step in reaching good environmental status, MS should establish monitoring programmes, enabling the state of the marine waters concerned to be assessed on a regular basis. Criteria and methodological standards on GES of marine waters were published in 2010 (Commission Decision 2010/477/EU). Two indicators were described for Descriptor 11 (Noise/Energy): 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 Subgroup (TSG) for further development of Descriptor 11 Noise/Energy. TSG (Underwater) Noise in 2011 focused on clarifying the purpose, use and limitation of the indicators and described methodology that would be unambiguous, effective and practicable; the first report [Van der Graaf *et al.*, 2012]<sup>1</sup> was delivered in February 2012. Significant progress was made in the interpretation and practical implementation of the two indicators, and most ambiguities were solved.

In December 2011, EU Marine Directors requested the continuation of TSG Noise, and the group was tasked with recommending how MS might best make the indicators of the Commission Decision operational. TSG Noise was asked first to provide monitoring guidance that could be used by MS in establishing monitoring schemes for underwater noise in their marine waters. Further work includes providing suggestions for (future) target setting; for addressing the biological impacts of anthropogenic underwater noise and to evaluate new information on the effects of sound on marine biota with a view to considering indicators of noise effects.

The present document is **Part II** of the **Monitoring Guidance for Underwater Noise in European Seas** and provides MS with the information needed to commence the monitoring required to implement this aspect of MSFD. TSG Noise has identified ambiguities, uncertainties and other shortcomings that may hinder monitoring initiatives and has provided solutions. Methodology is described for monitoring both impulsive and ambient noise to ensure the information required for management and policy is collected in a cost-effective way. Further issues will certainly arise once monitoring starts, but the principles laid out in this guidance will help resolve these.

The Monitoring Guidance for Underwater Noise is structured, as follows:

- Part I: Executive Summary & Recommendations,
- **Part II: Monitoring Guidance Specifications**, and
- Part III: Background Information and Annexes.

Part I of the Monitoring Guidance is the executive summary for policy and decision makers responsible for the adoption and implementation of MSFD at national level. It provides the key conclusions and recommendations presented in Part II that support the practical guidance for MS and will, enable assessment of the current level of underwater noise.

Part II, is the main report of the Monitoring Guidance, is the main report of the Monitoring Guidance. It provides specifications for the monitoring of underwater noise, with dedicated sections on impulsive noise (Criterion 11.1 of the Commission Decision) and ambient noise

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<sup>1</sup> The 1<sup>st</sup> TSG Noise Report (27 February 2012) available online:  
[http://ec.europa.eu/environment/marine/pdf/MSFD\\_reportTSG\\_Noise.pdf](http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf)

(Criterion 11.2 of the Commission Decision) designed for those responsible for implementation of noise monitoring/modelling, and noise registration.

Part III, the background information and annexes, is not part of the guidance, but is added for additional information, examples and references that support the Monitoring Guidance specifications.



# 1. INTRODUCTION

## 1.1 Introduction to Underwater Noise

Two indicators were published for Descriptor 11 (Noise/Energy) of the MSFD 2008/56/EC in the EC Decision 2010/477/EU on criteria and methodological standards on GES of marine waters. 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 EC Decision, the Marine Directors agreed to establish a technical sub-group (TSG) for further development of Descriptor 11 Noise/Energy. This report compiles the recommendations of TSG Noise. Text box 1 shows the extract of the EC Decision specifically for the indicators of Descriptor 11.

***Text Box 1: Extract of the indicators for Descriptor 11 (Noise/Energy) from EC 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 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 (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 1  $\mu$ Pa 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 Importance of noise versus other forms of energy

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 is underwater sound. It is likely that the amount of underwater sound, and therefore 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 these changes. The numbers of anthropogenic electromagnetic fields are increasing due to the increasing number of power cables crossing our seas but these



emissions are relatively localised to the cables. Light and heat emissions are also relatively localised, but may have significant local effects (Tasker *et al.* 2010).

Sound energy input can occur on many scales in both space and time. Anthropogenic sounds may be of short duration (*i.e.* impulsive) or be long lasting (*i.e.* continuous); impulsive sounds may however be repeated at intervals (duty cycle) and such repetition may become diffuse 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 which 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. injury, death). These adverse effects can be widespread (as opposed to localised for other forms of energy) and, following the recommendations of Tasker *et al.* (2010), in September 2010 the European Commission identified the main orientations for monitoring of underwater noise that should be used to describe Good Environmental Status (GES) [EC Decision 2010/477/EU on criteria and methodological standards on GES].

This report provides guidance to Member States for establishing monitoring programmes for these indicators of underwater sound.

## 2. GUIDANCE FOR REGISTRATION OF IMPULSIVE NOISE

Indicator 11.1.1 is described in the Commission Decision 2010/477/EU (CD) as: *Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1 $\mu$ Pa<sup>2</sup> .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.*

This description is not unambiguous and therefore TSG Noise recommends the following revision of the indicator 11.1.1 on low and mid-frequency impulsive sounds:

*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 source level or suitable proxy 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).*

For further considerations and explanation, see the first TSG report [Van der Graaf *et al.*, 2012].

### 2.1 Main objective and scope of the indicator

TSG Noise has noted that guidance is needed for the main objective of the impulsive noise indicator and the aim of the indicator was further explained in the first report by TSG Noise in February 2012. A basic principle of the MSFD is that it addresses the ecosystem rather than individual animals or species (consideration 5: the development and implementation of the thematic strategy should be aimed at the conservation of the marine ecosystems). This indicator addresses the cumulative impact of activities, rather than that of individual projects or programme (those are addressed by other EU legislation); effects of local/singular activities are not covered. This indicator alone is not intended, nor is it sufficient, to manage singular events, but Environmental Impact Assessments (EIA) can be used to assess, and where necessary, to limit the environmental impacts of individual projects.

TSG Noise suggested that “considerable” displacement is the most relevant effect of loud low and mid-frequency sounds that can practicably be measured - this may lead to population effects and thus should be addressed by Indicator 11.1.1. “Considerable” displacement means displacement of a significant proportion of individuals for a relevant time period and at a relevant spatial scale. The indicator addresses the cumulative impact of sound generating activities and possible associated displacement, where effects may occur at the ecosystem level; for further clarification see the first report of TSG Noise [Van der Graaf, 2012], par 3.3.1.3).

The purpose of this indicator is to quantify the pressure on the environment, by making available an overview of all loud impulsive low and mid-frequency sound sources, throughout the year, in regional seas. This will enable MS to get a complete overview of the occurrence of all the activities that produce the relevant sounds that place pressure on the environment, which has not previously been achieved. It will also make it easier to assess cumulative effects of the pressure on the environment (see the first report of TSG Noise [Van der Graaf, 2012]).

The initial step is to establish the current level and trend of these impulsive sounds. This may be done by setting up a register of these impulsive sounds.

## 2.2 Impulsive sound and most relevant sources

The Commission Decision uses the term “impulsive” sounds. TSG Noise realised that the term “impulsive” is reserved for specific sounds that are often transient, and which are characterised by a rapid rise time and high peak pressures. The term “pulse” is sometimes also used for these sounds including in widely accepted publications [Southall *et al.*, 2007]. The original intention of the indicator was that also other loud short-duration sounds were probably of relevance, e.g. sonar sounds [Tasker *et al.*, 2010]. These sounds would not be included in the definition of “impulsive” (or “pulse”) as used in some communities [Southall *et al.*, 2007]. Therefore TSG Noise concluded some clarification on the (use of) the term “impulsive” is needed.

The title of the indicator is “11.1. Distribution in time and place of loud, low and mid frequency impulsive sounds”. This text suggests that one needs to distinguish between impulsive sounds and non-impulsive ones, and a definition of “impulsive sound” was proposed in [Van der Graaf *et al.*, 2012]. A more careful reading of the indicator text:

“[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”

makes clear that the emphasis is not on “impulsive sounds” as such, but on sound of “short duration”, of which impulsive sounds are mentioned as an example.

For Indicator 11.1.1, the TSG Noise proposal is to monitor loud sounds of short duration that are likely to cause disturbance. Impact pile driving has been shown to result in an evasive response in harbour porpoises [Dähne *et al.*, 2013] and airguns have been shown to result in evasive reaction in many cetaceans [Stone and Tasker, 2006], and disturbance on fish may also occur [Dalen and Knudsen, 1986; Engås *et al.*, 1996; Slotte *et al.*, 2012]. Sonar transmissions have also been shown to cause a strong aversive reaction in beaked whales [Tyack *et al.*, 2011, DeRuiter *et al.*, 2013]. Therefore airguns, impact pile driving and sonar should be included in the scope of this Indicator. Most available data for explosions focuses on physical harm [e.g. Danil & St. Leger, 2011] rather than on disturbance, but these should also be included as sound levels produced by explosions are much higher than that of the above mentioned sources.

Whereas sounds produced by piling, airguns and explosions typically are short (less than one second), sonar sounds may be of longer duration, i.e. several seconds. To cover all sources of concern, TSG Noise proposes that all loud sounds of duration less than 10 seconds should be included.

## 2.3 Outline of the register (M1-b)

The main aim of the register is to record activities in order to enable assessment of the total pressure from impulsive sources. In addition to serving as an assessment tool, it is possible that the register may also serve as a tool to aid management decision-making in the future, once a baseline level has been determined and/or there are targets for the management of sound.

A noise register will provide data that could be used to map the occurrence of activities generating loud sounds. The amplitude, frequency and other impulsive characteristics of the sounds are not precisely defined in the Commission Decision, although the frequency range has been defined as 10 Hz to 10 kHz. The precise properties of an impulsive sound that cause displacement are not yet known, and are certain to vary with biological receptor and the time of year. An essential first step towards cumulative impact assessment is to map those human activities which are likely to generate “loud” impulsive sounds within this frequency range.

The most important sound-sources that should be considered for inclusion in the register are airguns, pile-driving, explosives, sonar working at relevant frequencies and some acoustic

deterrent devices. Additional sources that could also be of concern include boomers, sparkers and scientific echo sounders. TSG Noise proposes to use thresholds for inclusion in the register. Thresholds were derived that will ensure that all sources that have a potential for significant population level effect will be included in the register (see part III, chapter 2.1 for substantiation of the chosen thresholds). However, the use of these (relatively low) thresholds will result in sources with a relatively low potential for significant impact also being registered. TSG Noise concluded that there is a need for more detail in the register than just the day and location; of this additional information, the source level is the most important.

The main aim of the registry is to provide an overview of all loud sounds. If certain sound sources are left out, the aim of addressing the cumulative effects of impulsive noise would not be fully met, and therefore it is recommended that information on all sources should be included [see Van der Graaf *et al.*, 2012]. TSG Noise suggest that data on explosives and military activities (of which the sole purpose is defence or national security) should also be included in the register, but notes that this should be on a voluntary basis as this is a national policy issue.

### 2.3.1 Information to be included in the register

For the future register, the following data should be collected:

- ✓ Position data (geographic position (lat/long), licensing block/area)
- ✓ Date of operation
- ✓ Source properties:

Essential (minimum)

- Source level or proxy of source level;

Additional data will be beneficial for improved assessment - where available the following may also be recorded:

- Source spectra;
- Duty cycle;
- Duration of transmissions (and actual time/time period);
- Directivity <sup>2</sup>;
- Source depth;
- Platform speed

It is possible that many operators (e.g. navies using sonar) may have concerns about releasing sensitive information. Where detailed information of source properties is requested it is proposed that certain operators be given the option to report source level in bins (for example, in intervals of 10 dB) rather than giving a precise figure.

---

<sup>2</sup> Much of the energy from airguns is directed downwards, and therefore directivity data are needed to assess their significance. Directivity plots are routinely produced by seismic survey companies in advance of carrying out their surveys. If this information is made available (if possible in digital form), MS can include this information when assessing possible effect ranges and thereby improve the assessment. If for other sources the producer of the sound wants the directionality to be taken into account, that producer should provide the necessary information.

### 2.3.2 Issues for a common register between Member States

TSG Noise recommends the setting up of a joint register of the occurrence of impulsive sounds at least on a Regional Sea level.

The final format for the common register needs to be established to ensure future compatibility. This cannot be conclusively decided until the register location and management are decided, but some factors could be implemented now, such as:

- ✓ Use of a common language (English)
- ✓ Use of a common format for date in accordance with the appropriate standard (ISO 8601) (YYYY-MM-DD or YYYYMMDD)
- ✓ Use of a common format for position (latitude and longitude, decimal degrees)
- ✓ Use of a common map projection (unprojected data – WGS84)
- ✓ Use of a common template (i.e. setting out the order in which information is recorded)

### 2.3.3 The use of grids, grid definition and size

As mentioned above, for some of the data (e.g. seismic survey data) the use of a grid (based on standard licensing blocks) may be practicable to collect (part of) the data on impulsive noise. Member States may choose to use such a grid to organise data (for instance, use the above-mentioned blocks to store data instead of the actual positions of a piling activity). Member States may also choose to use such a grid for other purposes e.g. presenting data, assessment purposes and for future management action.

In such cases, the actual choice of grid definition, and the size of the grid cells, is a choice that should be made by Member States and this can be based on practical considerations, e.g. in the UK, data are registered in standard hydrocarbon licensing blocks that are 10 minutes latitude by 12 minutes longitude. If the grid is to be used for assessment purposes, a possible option is to base the grid on estimated impact (e.g. the reported range of displacement effects for harbour porpoises from pile driving has been of the order of 20 km [Tougaard *et al*, 2012]). A circle with a radius of 20 km has an area of ca. 1250 km<sup>2</sup>. TG 11 suggested blocks of 15 minutes of latitude by 15 minutes of longitude, which at a latitude of 45 degrees North, would give an area of about 550 km<sup>2</sup>. For easier interpretation of results in a common register, TSG Noise would recommend one standard grid size to be used by Member States.

If the grid chosen by Member States is to be used for assessment purposes, it should be noted that it may not be of the same spatial scale as the area actually affected by the noise source. The number of days (or proportion/percentage of a longer period) over which activities occur should not be interpreted as a direct measure of habitat loss (holes in distribution). This may not be a problem - a correction factor could be applied when comparing results that are generated using different grid sizes, or if the grid sizes are not appropriate for definitions of targets. This correction factor could, in principle, be based on the ratio of expected impact size to registry grid size. (see Van der Graaf *et al.*, 2012).

There may also be issues for grid cells in coastal areas or at boundaries between Member States. For these blocks some additional considerations may apply. See Part III of the guidance for more detailed information on these coastal and boundary blocks.

## 2.4 Technical Specifications

### 2.4.1 Thresholds (M1-a)

Minimum noise thresholds have been defined for low and mid-frequency sources as a basis for including sources in the register. For background and explanation of these values see Part III of the Monitoring Guidance (chapter 2.1)

For impact pile-drivers no minimum threshold should be used and all pile-driving activities should be registered.

For sonar, airguns, acoustic deterrents and explosives, minimum thresholds should be used for uptake in the registers. The generic source level (SL) threshold for inclusion in the register for non-impulsive sources is 176 dB re 1  $\mu\text{Pa m}$ , whereas the threshold for inclusion of impulsive sources is an energy source level ( $SL_E$ ) of 186 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$ . For airguns and explosives it is more convenient to convert these to proxies of zero to peak source level ( $SL_{z-p}$ ) and equivalent TNT charge mass ( $m_{\text{TNTeq}}$ ), respectively.

The recommended thresholds for these source levels and proxies of short duration sound sources are listed below<sup>3</sup>.

- |   |  |
|---|--|
| • Explosive:                                | $m_{\text{TNTeq}} > 8 \text{ g}$                                 |
| • Airgun:                                   | $SL_{z-p} > 209 \text{ dB re } 1 \mu\text{Pa m}$                 |
| • Other pulse sound source                  | $SL_E > 186 \text{ dB re } 1 \mu\text{Pa}^2 \text{m}^2 \text{s}$ |
| • Low-mid frequency sonar: <sup>4</sup>     | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$                       |
| • Low-mid freq. acoustic deterrent:         | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$                       |
| • Other nonpulse sound source: <sup>5</sup> | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$                       |

Where operators are given the option to report in bins instead of the specific level, the proposal is that they report source level as follows:

#### **Sonar or acoustic deterrents (source level, rounded to nearest decibel):**

- Very low: 176-200 dB re 1  $\mu\text{Pa m}$
- Low: 201-210 dB re 1  $\mu\text{Pa m}$
- Medium: 211-220 dB re 1  $\mu\text{Pa m}$
- High: above 220 dB re 1  $\mu\text{Pa m}$

#### **Generic explicitly impulsive source (energy source level, rounded to nearest decibel):**

- Very low: 186-210 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$
- Low: 211-220 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$
- Medium: 221-230 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$
- High: above 230 dB re 1  $\mu\text{Pa}^2 \text{m}^2 \text{s}$

#### **Airgun arrays (zero to peak source level, rounded to nearest decibel):**

- Very low: 209-233 dB re 1  $\mu\text{Pa m}$
- Low: 234-243 dB re 1  $\mu\text{Pa m}$

<sup>3</sup> This list of thresholds need to be updated regularly as techniques evolve. An example is marine vibroseis that may soon be used to replace airguns in shallow water and transition zone surveys.

<sup>4</sup> This threshold implies that all military search sonars would need to be included in the register (if MS opt to do so).

<sup>5</sup> For sources with a tonal character (sonars, deterrents and the generic non-impulsive source) the SL in the frequency band below 10 kHz is relevant.

- Medium: 244-253 dB re 1  $\mu$ Pa m
- High: above 253 dB re 1  $\mu$ Pa m

**Explosions (equivalent TNT charge mass, rounded to nearest 10 g if less than 10 kg and to nearest 1 kg otherwise)**

- Very low: 8 g to 210 g
- Low: 220 g to 2.1 kg
- medium: 2.11-21 kg
- high: 22-210 kg
- Very high: above 210 kg

**Impact pile driver (hammer energy<sup>6</sup>, rounded to nearest 10 kJ)**

- Very low: less than 280 kJ
- Low: 290 kJ-2.80 MJ
- Medium: 2.81-28 MJ
- High: above 28 MJ

## 2.5 Interpretation of results (M1-c&d)

The monitoring of indicator 11.1.1 will enable Member States to quantify the pressure on the environment from loud impulsive low and mid-frequency sound sources. Pressure indicators and pressure-based targets may be used in management if a clear understanding of the relationship between pressure, state and impact exists [Claussen et al., 2011; Borja et al., 2013].

More specifically, this indicator is designed to provide information describing temporal and spatial distribution of impulsive noise sources, through the year and throughout regional seas, to enable assessment of possible cumulative impacts of displacement on marine species at the population level. Current data on bio-acoustic impacts are mostly limited to short-term individual responses. Cumulative exposures from multiple noise sources over large geographic scales and long durations can be modelled, but not much is known about impacts of cumulative acoustic exposure. The data gathered in the register will enable MS to estimate the size of the area affected by anthropogenic impulsive noise sources. Using information on response thresholds in received levels for particular species, the area of displacement can be estimated. Further steps are needed to assess how displacement affects a species at the population level. This requires considerable research, even for well-studied species, and results are likely to vary between species. Some modelling approaches, such as the Population Consequences of Acoustic Disturbance (PCAD) and Population Consequences of Disturbance (PCOD) models (National Research Council, 2005) try to link noise characteristics to population effects and may aid understanding. The ecological consequences of displacement will depend on the duration and extent to which animals are displaced and also on whether alternative suitable habitat is available.

### Baseline

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<sup>6</sup> Mitigation technologies currently being developed (e.g. bubble curtains) may result in hammer energy on its own not being sufficient to describe the level, and this advice may need adaptation in the future



According to EC guidance<sup>7</sup> the baseline can either be defined as:

- a) *reference state or background levels: a state of the environment considered largely free from the adverse effects of anthropogenic activities (i.e. negligible impacts from pressures on the environment). This can be defined in relation to aspects of environment state (physical, chemical and/or biological characteristics), or to levels of pressure on the environment or impact (e.g. an absence of contaminants or certain impacts). This type of baseline is typically used to allow an acceptable deviation in state to be defined which acts as the target threshold value to be achieved.*
- Or;
- b) *A specified/known state (of the environment, or the pressures on the environment and impacts acting upon it) usually implying, due to the methods used to derive it, that it may not be a reference state. This type of baseline is typically used to define the state at a specified time, often with an aim that there should be no further deterioration in environmental quality or levels of pressures on the environment and their impacts and/or that there should be improvements in quality from that date. Targets are consequently set towards improvement in quality or to ensure no further deterioration.*

The impulsive noise reference state (type a) baseline) would be a state with negligible impacts from anthropogenic noise. Given the historic use of impulsive noise sources, which may have affected the population dynamics and distribution of sensitive species, there will be few areas where this type of baseline could be determined.

The register will describe the spatial and temporal distribution of impulsive noise sources. This quantified assessment can then be used to help decide policy targets and to establish type b) baseline for the current situation.

The use of discrete spatial blocks within the register may be practical for data analysis, but MS should realise that the actual size of the area affected by a source may vary depending on source level, background noise level and sound propagation characteristics. In addition, various marine organisms may be affected by different sound characteristics.

## Thresholds and targets

Noise indicators must be considered as part of a general process to evaluate the GES of the marine environment. The MSFD requires a holistic assessment of the impacts of different pressures on the different components of the marine ecosystem. Ultimately, the status (relative to GES) of a population or system will be determined by the cumulative impacts of all environmental pressures. For example, displacement may result in a loss of available habitat - this can be included in a cumulative effects model alongside direct human induced mortality to assess the population status relative to an undisturbed state. Whether the status of the ecosystem is “Good” relative to its undisturbed state will be a societal decision. Some such decisions have been made in existing legislation. For example, protected species under the Habitat’s Directive need to be maintained at favourable conservation status and an example of a societal decision for small cetacean by-catch is that populations should be restored or maintained at a certain level relative to carrying capacity (ASCOBANS, 1997)<sup>8</sup>. Work is ongoing to extend this approach to include other impacts such as noise.

There are several options for the setting of reduction targets, each of which needs further consideration once example registers are in place. The targets might include:

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<sup>7</sup> European Commission. 2012. Guidance for 2012 reporting under the Marine Strategy Framework Directive, using the MSFD database tool. Version 1.0. DG Environment, Brussels. pp164.

<sup>8</sup> ASCOBANS. 1997. MOP 2: Resolution on Incidental Take of Small Cetaceans. Bonn, Germany.



- a. A target on the maximum permitted number of pulse-block days in an assessment area
- b. A no-deterioration (i.e. stable or negative trends) target on the number of pulse-block days in an assessment area
- c. A percentage target on the assessment area affected due to noise disturbance -i.e. on any given day less than x% of the assessment area is lost due to noise disturbance

The possible targets fall into two basic types – those that relate to limits on noise producing activities (e.g. examples a and c) or those that relate to trends (e.g. example b). Although limits will have more biological significance and relevance to GES, there is currently insufficient information to set such limits. By contrast, a trend towards a reduction in noise producing activities would be certain to be moving towards GES in situations where the system was assessed not to be at GES due to noise. One approach to setting targets would be to start with a trend and then move towards limits as more data become available.

Article 10 of the MSFD, establishment of environmental targets, provides for environmental targets that will guide progress towards GES. Annex IV of the directive outlines characteristics to be taken into account in the setting of these environmental targets including 2(c) “operational targets relating to concrete implementation measures to support their achievement”.

Specific operational targets can help in terms of reduction of the levels of impulsive sound by tackling the sources. They can also be set to assess the effectiveness of measures implemented to reduce input from specific sources. Operational targets cannot substitute environmental targets, but will be helpful in terms of defining measures. Once measures are implemented, their success must be evaluated.

Examples for possible operational targets are:

- A target to minimize impact to acceptable levels by reducing noise output from certain sound sources
- [XX%]reduction in the number of piles which have pile driven foundations to encourage development of alternative foundation methods
- A restriction of pile diameters to xx meters in order to limit the noise generated.

### **Practical uses of the noise register**

The register can be used to estimate the spatial and temporal impact on the environment (the total period and total habitat loss by impulsive noise sources) and for determining the baseline level. Once a baseline and targets have been set, the register can be used for management purposes (e.g. regulating planning and licensing activities) and assist in marine spatial planning, incorporating displacement mitigation guidelines and reducing the potential for cumulative impacts.

### 3. MONITORING GUIDANCE FOR AMBIENT NOISE

This chapter provides a guide for monitoring ambient noise as covered in the EU MSFD indicator 11.2.1. This indicator is described in the Commission Decision:

- *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).*

The chapter begins with a brief introduction describing the indicator's scope. What follows are the definitions, as recommended by TSG Noise, for the essential terms of Indicator 11.2.1. Next, the report outlines key concepts of a monitoring programme for this indicator. It is beyond the remit of TSG Noise to provide a detailed guide for all European (sub) regions, but the cornerstone principles for monitoring/modelling, the technical specifications of equipment, and guidance on the use of averaging methods, will be provided. The chapter concludes with suggestions for the interpretation of the results.

There are no international standards for monitoring underwater ambient noise. Monitoring requires a combination of measurements and modelling, which means that standards are required to cover both aspects. Existing standards under development by the International Organization for Standardization (ISO) include a terminology standard<sup>9</sup> and several measurement standards<sup>10</sup>. The measurement standards, once complete, will facilitate the collection of valuable information about the sources of ambient noise (shipping and pile driving are being addressed); seismic surveys and explosions are also important sources of ambient noise, at least in the North Sea [Ainslie *et al.*, 2009]. The measurement standards do not address is long term ambient noise monitoring as required for the MSFD. TSG Noise therefore advises MS to follow some basic guidelines described in Sec. 3.3. TSG Noise also points out the need for International Standards for the measurement of underwater sound generally and for ambient noise in particular. In this regard, the U.S. National Oceanic and Atmospheric Administration (NOAA) has begun developing a forward looking Ocean Noise Strategy to provide long term direction to NOAA's management of Ocean Noise. Initial discussions have focused on conserving the quality of marine acoustic habitat in addition to minimizing more direct adverse physical and behavioural impacts on specific species. As part of the Ocean Noise Strategy initiative, NOAA has recently established a Soundscape Characterization Group. This group is in the initial phase of developing a framework for ocean noise monitoring in U.S. waters in which methods and techniques for characterizing and monitoring marine soundscapes will be outlined. Developing international standards for the measurement of underwater ambient noise would be of mutual benefit for both EU Member States and NOAA.

#### 3.1 Main objective and Scope of the indicator

Tasker *et al.*, (2010) and Van der Graaf *et al.*, (2012) provide the background on the concept behind Indicator 11.2.1. This indicator focuses on chronic exposure of marine life to low frequency, anthropogenic ambient noise. The main contributor, in many regions, is noise from commercial shipping, hence the initial choice of two frequency bands where the contribution of noise from shipping (relative to other sources, including natural) is likely to be greatest. Data suggests that exposure to elevated ambient noise from human activities could lead to the masking of biologically important signals. In the long term this could also induce stress in receivers which, in turn, may lead to physiological impacts (see review by OSPAR, 2009).

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<sup>9</sup> Working Group 2 of ISO/TC 43/SC 3 – Underwater Acoustics

<sup>10</sup> Working Groups 1 and 3 of ISO/TC 43/SC 3 – Underwater Acoustics and ISO/TC 8/SC 2-TC 43/SC 3/JWG 1

TSG Noise provides advice on scope and optimal approach, in making Indicator 11.2.1 operational. TSG Noise also provides clarification and detailed definitions of essential terms.

In addition to the advice relating to the indicator, TSG Noise discussed to what extent the monitoring of trends would be sufficient to reach the overarching aim of the MSFD, i.e. to ensure that Good Environmental Status is maintained. Within TSG Noise it was suggested that *trends only* are not sufficient to describe GES. To describe GES *levels*, based on a wider overview of the area, a combination of modelling / measurements and possible mapping will be needed.

The Working Group on Good Environmental Status (WG GES), in the “Common Understanding” document [Claussen et al., 2011<sup>11</sup>], advocates the use of a trend as an interim target “to ascertain whether progress is being made towards achieving GES ... until the evidence base supports the establishment of more quantitative environmental targets”. For example, the proposed target for anthropogenic nutrients: “A decreasing trend in dissolved organic nitrogen and phosphorous concentration, resulting from anthropogenic nutrient input over a 10 year period”.

Similar trend-based targets can be used for underwater noise. In a situation where GES was not achieved due to underwater noise then it would make sense to adopt a downward trend as an interim target. Although there is some evidence that cetaceans adjust their vocalisations according to noise conditions in much the same way as birds are known to, there is also evidence [Rolland *et al.*, 2012] that noise increases stress. It is therefore the opinion of TSG Noise that there is insufficient knowledge on the effects of increasing levels of human-induced ambient noise to determine whether existing levels are too high, or if GES is being achieved. However, if a Member State suspects noise levels are too high or on the increase, then that Member State may choose to target a downward (or non-increasing) trend in line with the precautionary principle described in the MSFD.

An indicator may be used by MS for target setting and programme of measures, where there is reasonable expectation of determining the indicator value, and where programmes of measures are required, on a timescale relevant to the adaptive management process, by Article 3 of the MSFD. At present, there are no data on longer-term trends of ambient noise in European waters, but some information is available that may make clear what MS can expect if they attempt to determine trends in European waters.

Long term (decadal) measurements in the north-east Pacific Ocean show an increase in the 63 Hz band of 5 dB in 35 years (between 1965 and 2000), which amounts to 1.4 dB per decade on average [Andrew *et al.*, 2011]. The 3.5-year time span series presented in Van der Schaar *et al.*, (2013) shows large fluctuations in measurements, with four hydrophone stations placed in three different oceans (also see chapters 2.8 for a description of this data set in Part III).

Although similar trends can be expected in deep water in other parts of the industrialised world, this cannot be confirmed by measurements in European waters, since no results or data are available. Even with a hindcast model it is difficult to verify the accuracy of the data. In shallow water, trends of ambient noise are likely to be different due to the different types of vessels in these waters and differing sound propagation conditions. It is not known whether the trends in shallow water are greater or lesser than in deep water, and this is further complicated by spatial variation, which is likely to be greater in shallower water. This variation is due, in part, to shorter distances to noise sources (increasing the likelihood of high amplitude transient sounds), although the variable propagation conditions typically encountered in shallow water is another factor. Spatial variation is expected to be much larger than yearly trends because some waters, such as harbour channels, are used to a far greater extent than in others.

Thus, it could take decades rather than years (and so much later than 2020) to establish statistically significant ambient noise trends for EU waters. From a practical point of view it is

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<sup>11</sup> EC Working Group on Good Environmental Status, Common Understanding of (Initial) Assessment, Determination of Good Environmental Status (GES) and Establishment of Environmental Targets (Art. 8, 9 & 10 MSFD), Version 6 – 22 November 2011, endorsed as living document at the meeting of the EU Marine Directors on 8-9 December 2011

preferable to measure levels, not trends, as levels can be measured on a timescale relevant to MSFD and compared with a target.

Consequently, to describe GES and to determine trends regarding sound levels, actual levels are needed, and understanding of the spatial and temporal variations is needed to identify an underlying trend.

In conclusion, it has been agreed that it is within the remit of TSG Noise, not only to describe how MS will monitor trends, but to advise MS on the best approach to determining actual levels (including a wider overview of the area, created with a combination of modelling and mapping). This will provide the option for MS to choose the most suitable approach when setting up monitoring. This guidance also addresses how MS can monitor actual levels (and thereby monitor trends) in a cost-effective way.

## 3.2 Definitions for ambient noise

TSG Noise has suggested a more precise definition of the original 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  $\mu$ Pa, either measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations [Van der Graaf et al., 2012].*

For monitoring it is important to clarify the terminology included in the above definition [see Van der Graaf et al., 2012]:

**Trend** should be defined as the general direction in which something is developing or changing. In the context of monitoring, “trend” refers to changes in a specific quantity, over periods of a year or longer.

**Annual averaged squared sound pressure level.** TSG Noise recommends that the averaging method for calculating annually averaged noise level is the arithmetic mean of the squared sound pressure samples. In order to establish the statistical significance of any trend, the distribution, in the form of percentiles, of the cumulative probability density function is required. This corresponds to percentage exceedance levels; the 50 % exceedance level is the median. For establishing the statistical significance of trends, the distribution in the form of exceedance levels is required (see also chapter 3.3.) The difference between the arithmetic mean and median is a measure of variability and skewness (i.e., lack of symmetry) of received levels.

The measured signal as displayed by Figure 1 has a typical structure for background noise and emerging ship noise when ships pass close to the hydrophone. Three types of averaging are displayed: the arithmetic mean, which reflects the presence of high amplitude transients; the geometric mean; and the median.

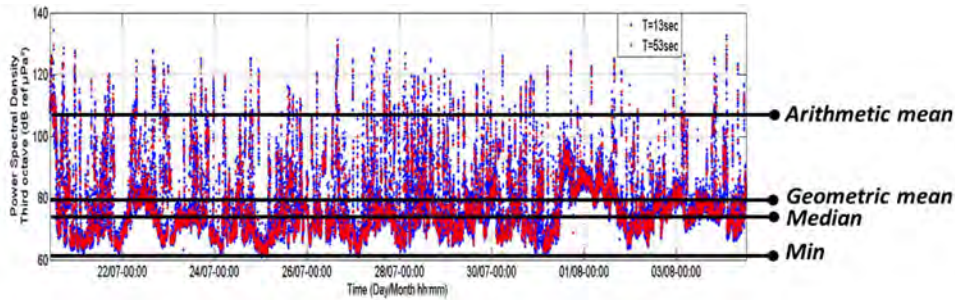


Figure 1: Example of approx. 14 days of continuous measurement in the 125 Hz third octave band made off Cork harbour (Ireland) entrance made during the STRIVE project (source: Quiet-Oceans).

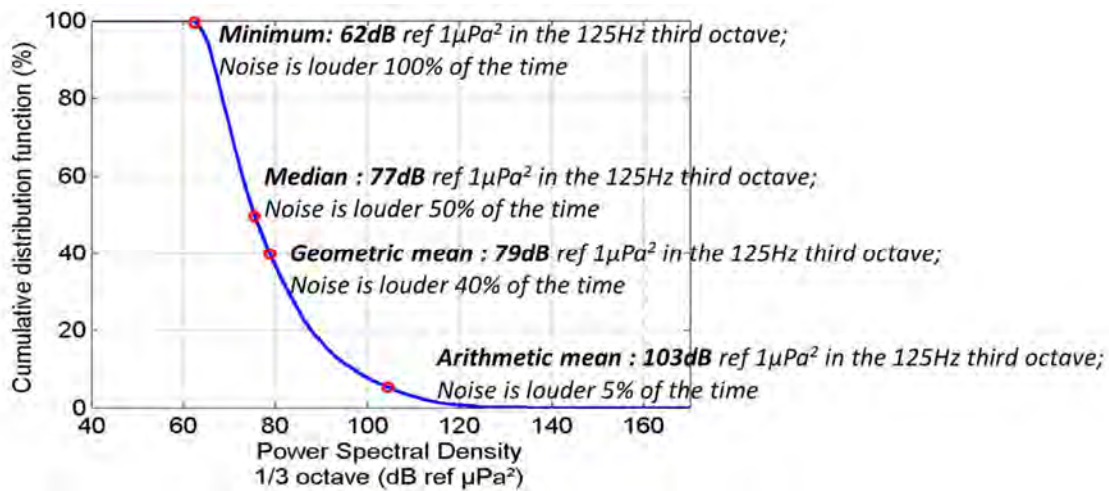


Figure 2: Statistical representation of the measured sound pressure level in the 125 Hz third octave band off Cork harbour as a cumulative distribution function, the exceedance<sup>12</sup>.

The curve shows the proportion of time where a given minimum level is reached. For example, it shows that 50% of the time, the measured level exceeds 77 dB re 1  $\mu\text{Pa}$ , and that the level exceeds the arithmetic mean only 5% of the time.

***N* percent exceedance level:** Level that is exceeded *N* times out of 100

<sup>12</sup> The term ‘exceedance level’ is preferred to ‘percentile’ because ‘10th percentile’ can mean either the value exceeded 10% of the time (10% exceedance level) or the value not exceeded 10% of the time (90% exceedance level). See [ISO 2003] ISO 1996-1:2003, INTERNATIONAL STANDARD ISO 1996-1, Second edition, 2003-08-01, Acoustics — Description, measurement and assessment of environmental noise —, Part 1: Basic quantities and assessment procedures



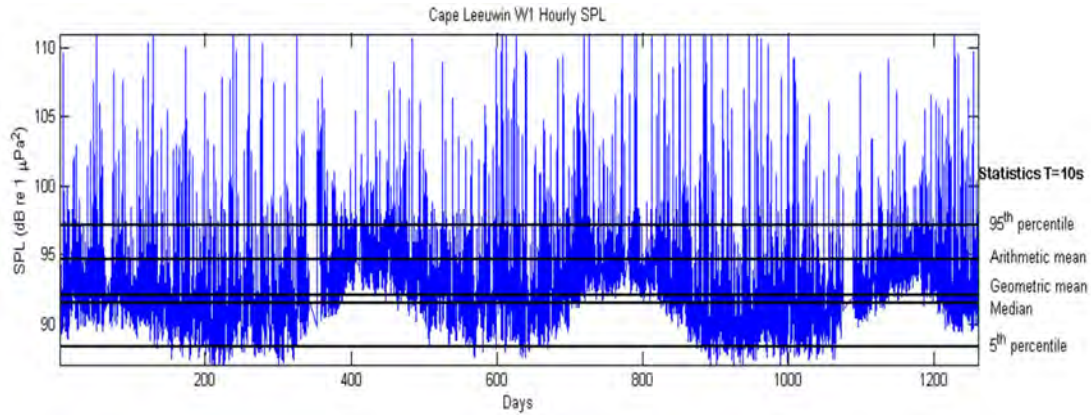


Figure 3: Example of 3 years of measurements in the 63 Hz third octave band made at the CTBTO Cape Leeuwin station.

The graphic of Figure 3 shows hourly summarised SPL measurements. The five statistics indicated on the right were computed over 10 second SPL measurements.

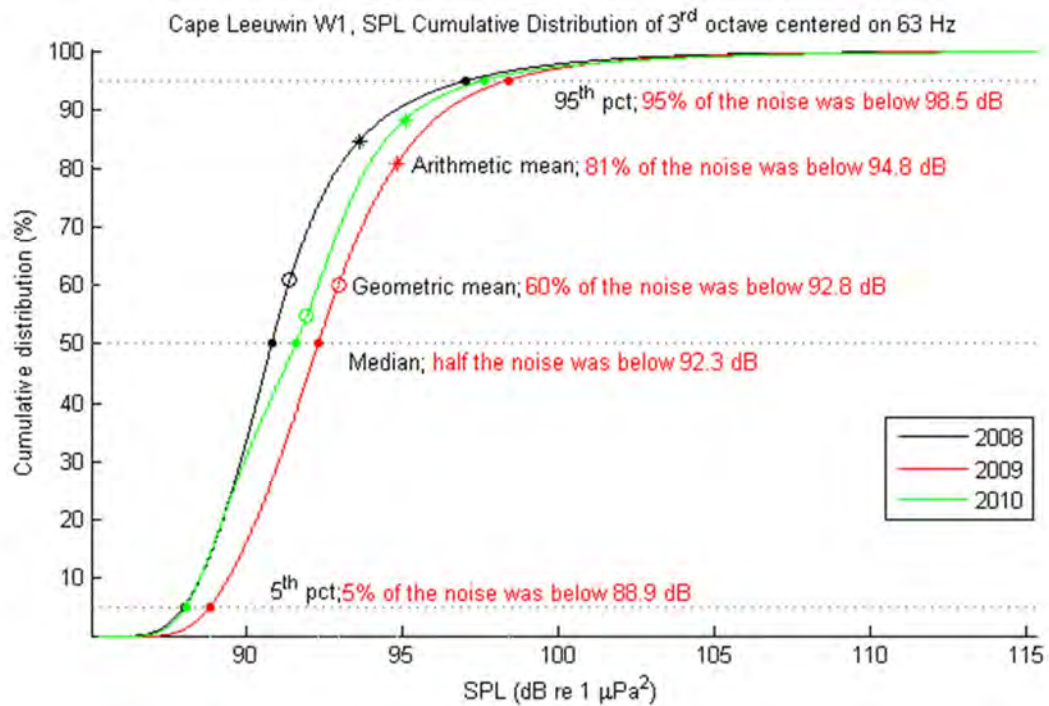


Figure 4: Cumulative distribution of the noise levels (SPL over a 10 second window) measured at the CTBTO Cape Leeuwin station during three consecutive years.

The curve of Figure 4 shows the proportion of measurements that were below a certain sound level. The five statistics on the right are interpreted for the year 2009 (red).

**Ambient noise** All sound except that resulting from the deployment, operation or recovery of the recording equipment, and its associated platform, where “all sound” includes both natural and anthropogenic sounds.

**Third octave bands** 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*. TSG Noise recommends that including third octave bands covering the frequency range up to 20 kHz be considered by Member States for recording and possibly in the analysis. The additional range specified will add relatively little to the operational cost but will provide potentially valuable extra data, which will contribute to the knowledge base, and may assist with the evaluation of the monitoring regime at the six-year revision.

### 3.3 Measurements and modelling

TSG Noise notes that the Commission Decision does not require Member States to describe the complete noise field in their waters. In theory, a limited number of monitoring stations (measurement locations) would be sufficient to fulfil the requirements of the indicator. TSG Noise has evaluated the advantages and disadvantages of different monitoring approaches.

TSG Noise considers measurements to be essential to ground truth the models, but results are sensitive to bias introduced by known changes in the spatial distribution of human activities, e.g. changes in ferry routes, or bias introduced by environmental and climatic variables. Measurements are logistically challenging at sea, therefore TSG Noise has researched whether modelling can be used to design a more comprehensive and cost-effective monitoring strategy. Modelling is a supplement to measurements and a properly validated model will increase utility of the measurement results.

#### 3.3.1 Models

Several kinds of models can be applied for data processing and predictive acoustic modelling. For an acoustic model for sound field simulation, the following parameters are needed:

- ✓ Model for the sources (possibly requiring different source spectra for different classes of vessel)
- ✓ AIS for location and class of vessel
- ✓ Environmental characteristics relevant to acoustic propagation (seabed characteristics, etc)
- ✓ Prediction of temporal variation to enable calculation of statistical distributions of noise

Validation of the model by comparison to measured data is required and, preferably, it should be benchmarked against standard test cases. Models maybe classified into a number categories (see Jensen *et al.*, 1994, Weston, 1959 and Weston, 1976):

- ✓ solution of Helmholtz equations
  - parabolic equation
  - normal mode approximation
  - wave number integration
  - ray tracing
- ✓ Energy flux model
- ✓ Boundary finite element and finite difference

### 3.3.2 The use of modelling

The use of modelling for indicators and noise statistics, and possibly the creation of noise maps, ensures that trend estimation is more reliable and cost-effective, for the following reasons:

- i. Use of models reduces the time required to establish a trend, with a fixed number of measurement stations (the expected trend in shipping noise, based on observations in deep water, is of the order of 0.1 dB/year; and therefore it takes many years, possibly decades, to reveal such small trends without the help of *spatial averaging*)
- ii. Use of models reduces the number of stations required to establish a trend over a fixed amount of time (similar reasoning), therefore reducing the cost of monitoring
- iii. Modelling helps with the choice of monitoring positions and equipment (selecting locations where the shipping noise is dominant as opposed to explosions or seismic surveys being dominant).

The use of models enables individual identification of trends for different sources, thus identifying the cause of any fluctuations, which could facilitate mitigation. Furthermore, models allow the removal of selected sources if these are not considered to cause a departure from GES (such as natural sound sources, both biotic and abiotic (e.g. lightning)).

The use of models provides MS with an overview of actual levels and their distribution across the sea area, thereby enabling identification of a departure from GES.

In addition, there are advantages of using modelling that could contribute to a greater understanding of potential impacts of noise, such as:

- ✓ Use of models enables forecast of changes and their effects (e.g. what is the expected effect of certain percentage increases in shipping traffic in the eastern Baltic over the coming years?) as well as construction of a past history (hindcast). New ships may have different noise signatures to their earlier equivalents which may further affect results.
- ✓ Use of models enables compilation of an ex ante estimate of the efficacy of alternative mitigation actions.

TSG Noise concludes that the combined use of measurements and models (and possibly sound maps) is the best way for Member States to ascertain levels and trends of ambient noise in the relevant frequency bands. Member States should be careful to balance modelling with measurements.

### 3.3.3 Available knowledge on noise mapping and possible applications

Noise mapping is a form of spatial modelling, and is explored here as it provides a convenient and accessible way to visualise such models. A noise map can be used, in management and in the evaluation of measurements. Several Member States have produced noise maps. These are listed below and are described in more detail in part III:

- Noise maps of shipping and explosions in the Dutch North Sea. This provides an overview for the potential of such maps, and how they can be used to identify locations where the soundscape is dominated by specific sources. In addition the study demonstrates how noise maps may help in choosing suitable locations for measurement stations.
- Noise modelling and mapping in Irish waters demonstrates how sound maps, relating to shipping, can be produced using data from an Automated Identification System (AIS). Using this data, the noise prediction system can calculate the noise field associated with



specific anthropogenic activities, including noise statistics which depend on seasonal variations of environmental factors, as well as shipping variability

- The Baltic Sea Information on the Acoustic Soundscape (BIAS)<sup>13</sup> project aims to establish a regional implementation of noise monitoring, which includes the development of tools to manage and describe of sound levels. In order to enable efficient, joint management, the project also aims to establish regional standards and methodologies for handling data and results. Measurements will be done at 37 locations in the Baltic Sea. The measurements will be used in models to produce soundscape maps.
- Work on noise modelling and mapping in German waters has been funded by the Federal Environment Agency (UBA) and recently concluded a mapping software SEANAT (Subsea Environmental Acoustic Noise Assessment Tool). A modelling approach is used which is based on measurements of ambient noise and relevant sound sources. The software is created to allow modelling of the underwater sound fields in the EEZs of the German Baltic and North Sea and imaging species-related impacts on organisms (more information available in part III chapter 2.6).

Member States have decades of experience of airborne noise monitoring and mapping. This earlier European experience should be used in developing underwater noise monitoring. Further information is available on noise mapping in air in part III chapter 2.7, including the relevant EU regulation (the Noise Directive), including useful background information that can assist in implementing the MSFD.

### 3.4 Outline of the monitoring programme

TSG Noise advises MS, within a sub region, to work together in setting up ambient noise monitoring systems. Without knowing how MS will work together, TSG Noise cannot define exact locations for monitoring, but suggest an initial set of considerations for the placement of devices based upon Tasker *et al.*, [2010], Van der Graaf *et al.*, [2012] and further discussions within TSG Noise.

This indicator is designed to monitor ambient noise at specific frequencies. The frequency bands were chosen to focus monitoring of ambient noise on the contribution of shipping. For MS, it makes sense to design monitoring programmes based on shipping for this very reason. In addition, patterns of shipping tend to remain consistent over many years compared to other noise sources, such as seismic surveys, which may contribute more noise energy but display varied noise distribution patterns.

The prime objective for the monitoring programme is to establish the trend. However, since the benefit of using models is acknowledged, the monitoring programme should pursue two linked objectives with separate specific monitoring strategies:

- ✓ **Category A Monitoring** - to establish information on the ambient noise in a location and to ground truth noise prediction,
- ✓ **Category B Monitoring**- to reduce uncertainty on source levels to be used as the input for modelling.

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<sup>13</sup> BIAS information: <http://www.bias-project.eu>

### **Category A Monitoring - to establish information in a location and ground-truth noise predictions**

Low-frequency sound propagates over long distances, and the frequency bands defined by the MSFD are likely to be dominated by shipping lanes throughout Europe's seas. Therefore, for this purpose, it is best to place hydrophones at locations which are remote from shipping lanes in order to monitor the diversity of noise contributions in a more balanced way. Such a strategy is suitable for regional monitoring, and only a limited set of measuring stations per region would be needed to satisfy the requirements of the first objective. Good information on spatial distribution of activities in each region, and region-wide sound propagation characteristics, such as temperature and salinity, surface waves, etc., need to be monitored as well as the noise field. In waters less than 3000 m sensors should be deployed in the interval 30 to 100 times the water depth, measured from the closest edge of a shipping lane. In waters greater than 3000 m sensors should be deployed at a distance of at least 90km from the closest edge of a shipping lane. It should be stressed that, in water depth of 3000 m or greater, convergence zones (strong local maxima due to sound focusing [Urick 1983]) are likely to form at distances of 45-60 km from the sound sources. If the distance to the closest shipping lane is 60 km or less there is a risk that the measurements are sensitive to small shifts in oceanographic conditions or the precise location of the shipping lane. For these reasons a minimum distance of 90 km from the closest shipping lane is recommended. For this form of monitoring, hydrophones should be placed near to the seabed, although the actual design of the rig, and thus the depth of the hydrophone, is site dependent.

### **Category B Monitoring - to reduce uncertainty in noise models**

Noise measurements at an appropriate and relatively close distance to a shipping lane can be combined with data on individual vessels (from a system such as Automated Identification System (AIS)) to provide data on vessel source levels. Estimates of these levels could be used to describe individual sound sources as input for models. It is anticipated that only a limited set of such measuring stations would be needed to fulfil this form of monitoring since, in most regions, a large majority of ships follow the same routes. For a well-defined shipping lane, the measuring station location should be about 100-500 m outside the lane (measured from the edge as specified by the nautical chart); for a less well-defined shipping lane similar positioning should be attempted based on local information. For this type of monitoring the hydrophones should be placed at the closest depth to the minimum of the sound speed.

Following these points, TSG Noise recommends an initial set of guidelines for placement of measurement devices:

- 1- Where there are few measuring stations per basin, priority should be given to monitoring in order to ground truth predictions (category A), since this monitoring is less sensitive to the influence of individual ships that might bias the averaged sound pressure levels. Monitoring may be more cost effective if existing stations are used for monitoring other oceanographic features;
- 2- Member States should make sure that they have access to data on the noise characteristics of individual ships
- 3- In deep water, monitoring devices to ground truth predictions (category A) should be placed in areas of low shipping density. The range at which elevated noise levels may occur is greater in deep water as low frequency sound can propagate long distances;
- 4- Consider local topography and bathymetry effects e.g. where there are pronounced coastal landscapes or islands/archipelagos it may be appropriate to place hydrophones on both sides of the feature;
- 5- In waters subject to trawling, use locations that are protected from fishing activities or locations where trawling is avoided due to bottom features (e.g. underwater structures/wrecks) and/or to use trawl safe protection;
- 6- As far as possible avoid locations close to other sound producing sources that might interfere with measurements e.g. oil and gas exploration or offshore construction

activities. Areas of particularly high tidal currents may also affect the quality of the measurement;

- 7- In all underwater noise monitoring, the location should be chosen taking into account site-specific properties such as tide, sediment and currents; it is important that the rig is silent and rig design should take account site-specific considerations.
- 8- Calibrate sensors at the same pressure as encountered at the planned deployment depths (for clarification see part III chapter 2.10)

### **Planning sensor locations**

Factors that need to be taken into account when deciding on the positions for sensor locations include shipping density, convergence/divergence of shipping lanes, water depths, fishing activities, seismic surveys and areas of special interest. The relative importance of these factors will vary depending on region and thus no one “recipe” is possible. In deciding locations MS will have to prioritise among these factors. The numbers of, and location of the sensors will also depend on the characteristics of the area. Sensors can be used to monitor a sea, basin, coast, or even a marine sanctuary. Some of these factors are further explained in this section, but cost will be an important factor in restricting the number of sensors and the area covered.

Maps of shipping density should be consulted when considering potential locations for hydrophones. The characteristics of each potential location can then be examined for other noise generating influences (off-shore construction, planned seismic surveys or intense seasonal fisheries). As mentioned above, locations close to loud, but short-term, noise sources should be avoided. At finer spatial scales the detailed characteristics of possible locations can be examined for rates of tidal current, bottom type, and risks to the monitoring station from fishing activities. In addition, monitoring may be undertaken for other purposes than for the MSFD indicator, for example within an area designated for marine life vulnerable to underwater noise. It may be convenient (and reduce overall cost) if MSFD monitoring is conducted in these areas also.

### **Establishing the shipping density**

Annual and seasonal ship passages at specified sections or areas can be established making use, where available, of Automated Identification System AIS and Vessel Monitoring System (VMS) data. Density maps of shipping are essential for making decisions on sensor positions; an example is given in fig. 5 and fig. 6, where the numbers of ship passages (not including fishing vessels) are presented for the Baltic Sea.

Shipping density can be expressed in a number of ways: transit through an area, total distance travelled within an area or the number of vessels within an area. The annual average surface density of ships per unit area is probably most relevant in terms of noise. If such densities are generated for the region of interest, then the average density for various distances from any location can be estimated. Data from AIS, and particularly satellite AIS (s-AIS), can be used for analysis of shipping density, with appropriate adjustments in high density areas [Eiden and Martensen, 2010].

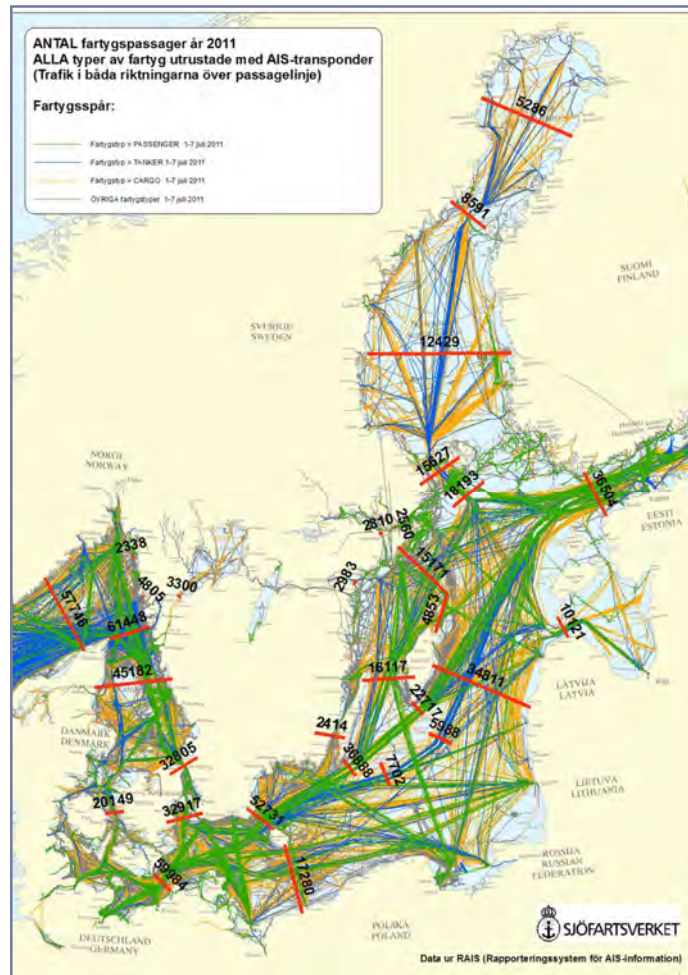


Figure 5. Ship traffic 2011 at the major transects in the Baltic Sea. Numbers in black indicate the overall ship routes in both directions over the red line during 2011. Green: passenger ships; blue: tankers; orange: cargo ships; grey, other ships (source Swedish Maritime Administration).

### Inclusion of special areas

Member States may consider including marine protected areas, such as marine reserves or Natura 2000 sites in the monitoring programme. Some protected areas are closed to trawling, which may make them a safer place for the monitoring station, while there may be an interest in establishing noise levels to help in conserving or managing some of the site’s features. However, TSG Noise recommends that relationship of the location relative to shipping lanes be considered *before* considering special areas.

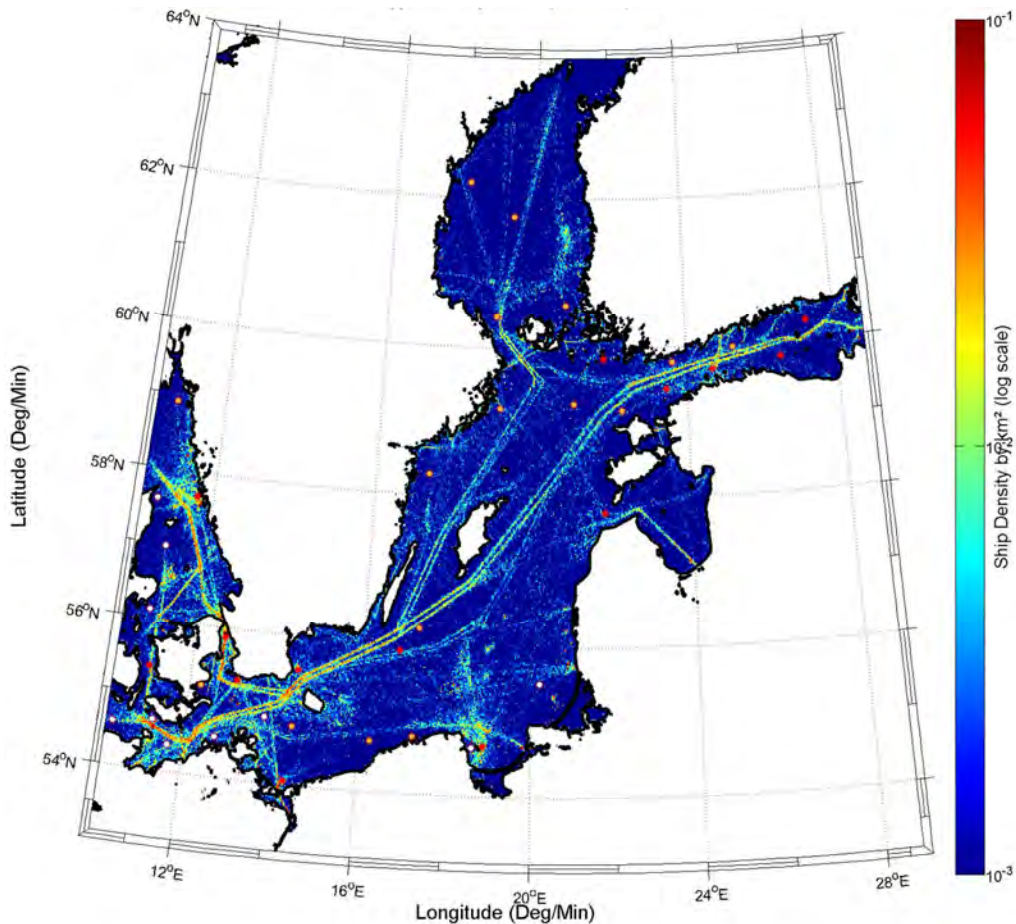
### Finer scale considerations

When the final positions are established, special concern should be given to the finer scale considerations of these positions. As was pointed out earlier the deployment area should be chosen to avoid short-term noise sources that might potentially affect sound levels. Information on fishing activities might also be used to avoid loss of sensors due to unwanted trawling events. Trawling normally occurs at low speeds (less than 5 knots), and trawling activities in the region can be established, for example, by using Vessel Monitoring Systems (VMS) data, thus indicating areas to be avoided. The sensor position can be adjusted to an area with lower fishing frequency, but only an area without trawling will provide substantially lower risk of loss. Information on



shipwrecks, wave buoys or other oceanographic measurement stations can also be used to avoid fishing activities, by adjusting the final position to be nearby one of these structures.

It should be underlined that acoustic properties of an area might vary spatially and temporally. The adjusted position should be as representative as possible of the conditions for the area, such that the data can help relate known sources of noise to the measurements in a way that allows predictions across a wider area from similar noise sources. For example sediment, depths and sound profile of the adjusted location should be representative of the area.



**Figure 6: Example of monitoring strategy implemented in the framework of the BIAS project.** The background of the image is the ship density for all activities described by AIS data. The dots show the locations of category A and category B monitoring stations.

### 3.4.1 Guidance for presenting the results

Processing of either the measurement and/or the modelling output can provide local or basin-scale statistics of the annual noise in the form of percentage exceedance levels (see Section 3.2). The rationale that led to Indicator 11.2.1 was associated with a concern that anthropogenic noise might mask important acoustic cues [Tasker *et al.*, 2010]. Masking can occur from both continuous and intermittent transient sounds (air gun pulses, passing ships, etc.). The relative potential for masking by continuous and transient sounds is still unclear. For future evaluation of trends (and potentially for setting targets), information on the relative contribution of the various sound sources may be needed. For this reason, TSG Noise considers that information about amplitude distribution versus time is needed. Therefore, TSG Noise recommends that complete distribution be retained in the form of sound pressure levels as a function of time, along with a specified averaging time. If it is not possible to store the full time series, TSG Noise

advises the retention of the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration (see also Part III chapter 2.8). TSG Noise advises MS that the snapshot duration should not exceed one minute.

### 3.4.2 Guidance for interpreting results and setting a baseline

Monitoring indicator 11.2.1 will enable MS to quantify the environmental pressure (expressed as ambient noise level) as well as trends in ambient noise levels within the two frequency bands. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists [Claussen *et al.*, 2011; Borja *et al.*, 2013]. Since there is very little information available on the effects of increased ambient noise level, and almost no information that describes the effects in a way usable for any quantitative assessment, TSG Noise cannot give concrete advice on interpretation of results at this stage.

As described in the chapter 2.4, a baseline can either be defined as: *a) reference state or background levels, or b) a specified/known state.*

For ambient noise, the baseline that MS should aim to set is the second of the two options. It is unlikely there will be many areas of open sea in European Seas which can be seen as a reference state free from influence from anthropogenic ambient sound in the two frequency bands. Some nearshore sheltered waters may be relatively free of these sounds, but may be atypical in other ways as they will have hydrography typical of nearshore areas and may suffer from reverberation problems. If it is possible to distinguish between natural and anthropogenic sources then models could be used to estimate baseline noise levels which would be expected in the absence of anthropogenic inputs.

Targets could be set based on either limits or trends, but, as for impulsive noise sources, there is currently likely to be insufficient information to set limits. In areas where anthropogenic noise has substantially raised ambient noise levels it may be appropriate to set initial targets based on trends. In these situations a trend towards reduced ambient noise would be more likely to be moving towards GES than if levels increase. An initial target based on trends could be augmented by limit based targets in the future as more quantified information on impacts becomes available.

## 3.5 Technical Specifications

### 3.5.1 Specifications for measuring equipment (M2-a)

In recent years, there have been an increasing number of commercially available, autonomous devices to address the need for *in situ* measurement of underwater noise. Their use is motivated by the need to monitor underwater noise, including in response to the requirements of Indicator 11.2 of the EU Marine Strategy Framework Directive. Such systems can provide cost-effective instrumentation for monitoring underwater noise, but the performance of these systems is crucial to the quality of the measured data.

Recent work by the National Physical Laboratory (UK) suggests that the performance of some commercially available systems may limit their usefulness for the absolute measurement of underwater noise. Some noise recorders on the market are converted from systems designed for other purposes, where absolute calibration is not required, and high quality recordings are not essential (detecting marine mammals). These issues were discussed in detail in the 2012 TSG Noise report [Van der Graaf *et al.*, 2012]. However, with the advent of commercial systems, TSG Noise emphasises the importance of calibration and performance issues in procuring systems for use in noise monitoring. Users should ensure that the equipment performance meets the needs of the measurement requirement, and make specific requests of suppliers with regard to certification and performance.

To prevent procurement of inadequate monitoring equipment, and in order to ensure that noise monitoring initiatives by Member States will be done in a cost-effective way and lead to correct data gathering, TSG Noise therefore provides advice on specifications for noise monitoring systems, as well as quality assurance and calibration of the equipment.

### 3.5.2 Equipment specification, quality assurance and calibration

The principal requirements for ensuring quality of measurements may broadly be categorised as follows:

#### Methods/procedures

The measurement method chosen must be appropriate for the task, and should be described by a suitable procedure, which may comprise written protocols or instructions.

#### Staff

The staff undertaking the work should be suitably trained and (ideally) have experience in the technical area.

#### Equipment

The equipment used must be fit for purpose, with a suitable performance, and must be calibrated traceable to appropriate standards.

This section deals with the requirements of the equipment, but it should be remembered that this is not the only requirement for a high quality measurement to be assured.

### **Background scientific literature**

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 [e.g. Wenz 1962, Macdonald *et al.* 2006, Cato 2008, Andrew *et al.* 2011, Dudzinski *et al.* 2011]. Though some of these papers relate to noise measurement in deep water, there are many common considerations when considering measurements in relatively shallow European waters.

### **Use of autonomous recorders**

Commercial autonomous recorders for use in measuring underwater sound are becoming increasingly available. Such recorders consist of a hydrophone connected to an electronics pod containing amplifier, ADC, data storage media and batteries to power the unit. These devices are often highly cost-effective, and have greatly increased the capability for ocean noise measurement without the need for bespoke designs that require great expertise to set up and operate.

When selecting an autonomous recorder, the performance of the recorder must be “fit-for-purpose” for the application. Some designs have been adapted from equipment designed to perform other tasks, and may not be well suited for use in making absolute measurements of sound. Users should ensure that the equipment performance meets the needs of the measurement requirement, and make specific requests of suppliers with regard to certification and performance. The key performance parameters listed in the following sections apply equally to autonomous recorders as they do to systems comprised of separate components.

### **Hydrophone and recording system performance**



### Frequency range

The only 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 these third-octave bands. Therefore, it is desirable that the measurement system used cover at least the frequency range 10 Hz to 20 kHz; the additional range specified above will add little to the operational cost but will provide extra data that will contribute to the knowledge base and may assist with future evaluations of the monitoring regime. Note that where other performance parameters may vary with frequency, these should also be determined over the full frequency range of the recording system.

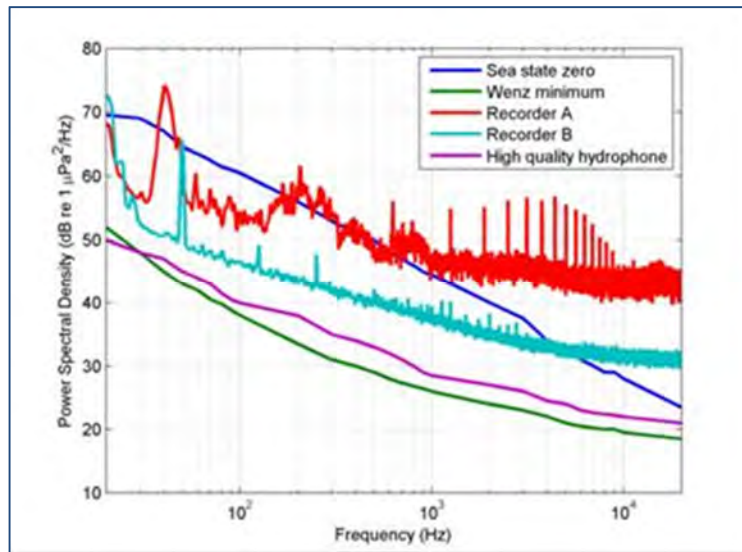
The requirement for unambiguous representation of the signals within the desired frequency band requires the sampling frequency of any Analogue to Digital Converter (ADC) within the recording system to be greater than two times the maximum acoustic frequency of interest. The maximum frequency of interest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

### System Self-Noise

The self-noise of the system is an important parameter when measuring ambient noise. Self-noise arises from two sources: (i) noise generated by the hydrophone and recording system; (ii) noise generated by the deployment platform or mooring. Such noise can contaminate the measured acoustic data, so ideally it should be minimised and at least measured and understood.

The system self-noise is normally expressed as a noise-equivalent sound pressure level in dB re 1  $\mu\text{Pa}^2/\text{Hz}$  (IEC 60565, 2006). The self-noise varies with acoustic frequency and as a result is usually presented as a noise spectral density level versus frequency. The noise equivalent pressure may be calculated by measuring the system electrical noise and dividing by the system sensitivity, where the measurement is made without any external acoustic stimulus present. Note that although the system self-noise may be expressed in terms of a noise equivalent sound pressure level, the origin of the noise is purely electrical from the hydrophone, amplifier and electronic components. The self-noise can originate from sub-standard hydrophones and amplifiers, or from pick-up of electrical noise generated by the electronics and data storage system.

It is common to compare values for self-noise with classic empirical curves for ambient noise levels in the ocean, such as those of Wenz [Wenz 1962] and Knudsen [Knudsen 1948]. Fig 7 shows these curves along with measured system self-noise data for a high-quality low-noise hydrophone, and two other recording systems. The low-noise hydrophone has been designed to optimise the noise performance, and the self-noise of such a system can approach Wenz's lowest ocean noise levels. Systems where the self-noise is not one of the key design parameters (recorder systems A and B in Figure 7) are likely to have a higher noise floor.



**Figure 7:** Noise spectral density data showing the performance (self-noise) of two recorder systems and a high quality low noise hydrophone. Also shown are the values for sea state zero and Wenz's minimum noise spectra. [Hayman *et al* 2013]

To achieve an 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 at 63 Hz and 125 Hz, which include distant shipping noise, are approximately 64 dB re 1  $\mu\text{Pa}^2/\text{Hz}$  and 59 dB re 1  $\mu\text{Pa}^2/\text{Hz}$  respectively. Without shipping noise, the noise level can be lower still. For example, Reeder *et al* (2011) reports approximately 53 dB re 1  $\mu\text{Pa}^2/\text{Hz}$  at 63 Hz and 49 dB re 1  $\mu\text{Pa}^2/\text{Hz}$  at 125 Hz in quiet conditions at the USN Atlantic Undersea Test and Evaluation Center. For a system designed to measure in a very low noise situation, we recommend a maximum self-noise which is 6 dB below these values (i.e., 47 dB re 1  $\mu\text{Pa}^2/\text{Hz}$  at 63 Hz and 43 dB re 1  $\mu\text{Pa}^2/\text{Hz}$  at 125 Hz). For measurements of higher noise levels (for example, for deployment close to shipping lanes), these requirements may be relaxed somewhat, but the self-noise should still be at least 6 dB below the lowest noise level of interest.

### Dynamic range

The dynamic range of the measuring system is the amplitude range over which the system can accurately measure the sound pressure. This ranges from the noise floor of the system (which defines the lowest measurable signal) to the highest amplitude of signal that may be measured without significant distortion. The system dynamic range should be chosen to be sufficient to enable the highest expected sound pressure to be recorded accurately without distortion or saturation caused by the hydrophone, amplifier and Analogue to Digital Converter (ADC).

When measuring low amplitude signals, care is required to ensure that not only will the signal amplitude exceed the noise floor of the system, but also that the recorded signal is not so low as to suffer from quantisation noise due to the poor resolution of the ADC for very small signals. The resolution of the ADC should be at least 16-bit (some are now available at 24 bits). With the use of modern high-resolution ADCs this is less of a problem than in the past. However, the system settings should be chosen to achieve recorded signals of appropriate resolution.

Some commercial systems may suffer from relatively limited dynamic range so that the large amplitude signals that can be detected at low frequencies can sometimes saturate the recorders. An ideal system would have 24-bit resolution, and be capable of measuring up to 180 dB re 1  $\mu\text{Pa}$  to record vessels passing close by. This is challenging, and many systems will not achieve the dynamic range in combination with the self-noise requirements, but in any case the actual

dynamic range should be known so that the maximum undistorted signal level can be estimated, and any saturated signals eliminated during analysis of the data.

A method to mitigate problems with dynamic range is to have some flexibility in the sensitivity, often achieved by use of adjustable gains for amplifier stages and scale settings on ADCs. However, where a system has been deployed remotely (for example, an autonomous recording system which is left in-situ for an extended period), there may be no control over the system settings after deployment. Here, some knowledge of the likely range of sound pressure levels is required to optimise the available dynamic range (this knowledge can be obtained from reported levels in the scientific literature or from approximate theoretical calculations). The required dynamic range can vary with acoustic frequency such that the low frequency components may be much higher amplitude than the high frequency components. One method to overcome this problem is to use a measuring system which consists of several channels, each of which is used to measure a specific frequency band [Lammers *et al* 2008]. For each of the frequency bands, the amplifier gain setting, the ADC scale setting and even the hydrophone can be chosen to match the expected sound pressure levels and achieve good quality data that is significantly in excess of the noise floor but without distortion or saturation. A disadvantage is that the system is far more complex, requires more calibration, and requires processing such that the data for each frequency band is integrated to form an overall spectrum; per situation, Member States need to verify that measuring other frequency bands than the two bands described in the indicator does not lead to disproportional cost.

#### Sensitivity

Ideally, the sensitivity of the hydrophone and measuring system should be chosen to be an appropriate value for the amplitude of the sound being measured. The aim in the choice of the system sensitivity is to:

- avoid poor signal-to-noise ratio for low amplitude signals;
- avoid nonlinearity, clipping and system saturation for high amplitude signals.

The sensitivity of the system must be known in absolute terms from a calibration, which should be the result of a measurement as indicative or nominal values produced at the system design stage may not be reliable. 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 from  $-165$  dB re  $1$  V/ $\mu$ Pa to  $-185$  dB re  $1$  V/ $\mu$ Pa.

#### Directionality

Ideally, a hydrophone would have an omnidirectional response such that its sensitivity is invariant with the direction of the incoming sound wave. In such cases, the orientation of the hydrophone during measurements would be unimportant. For the two third-octave bands of 63 Hz and 125 Hz required by the indicator, the assumption of an omnidirectional response should be valid.

However, omnidirectionality is only an approximation valid at low frequencies where the hydrophone size is a fraction of the acoustic wavelength. When the hydrophone size is significantly greater than the acoustic wavelength at the frequency of interest, the hydrophone will exhibit a response that shows appreciable directionality. In practice, for typical measuring hydrophones, this becomes a significant issue only at tens of kilohertz. However, one issue that can cause enhanced directionality is where the hydrophone is deployed close to another structure that is capable of reflecting the sound waves. The combination of the direct waves and reflected waves causes interference, the nature of which will change depending on the arrival angle for the sound wave. This effect may be evident at low kilohertz frequencies if the hydrophone is deployed close to a support structure such as a heavy mooring or support. In particular, this effect may occur when using an autonomous recorder where the hydrophone is

attached or positioned close to a recorder case that houses electronics and batteries but is mostly air-filled. This configuration should be avoided if an omnidirectional response is required at kilohertz frequencies.

#### Data storage

To avoid degradation of the data quality, the data format used to store the data should be lossless. Any crucial auxiliary data or metadata which is needed for interpretation of the results (for example, the scale factor or setting of the ADC) should be recorded. It is desirable that such information be included in a file header or log file so that the information is kept with the data. Though a number of suitable data formats exist, there is no standardised format for storing ocean noise data. TSG Noise recommends that issue is addressed in future standards for ambient noise measurements.

### **3.5.3 Calibration of equipment**

#### **System calibration**

For an absolute measurement, the sensitivity of the measuring system must be known. This requires that the system be calibrated. A laboratory calibration requires that the system undergo a series of measurements to determine the sensitivity. Indicative or nominal calibration values produced at the system design stage are not reliable and should not be used. The calibration should cover the full frequency range of interest for the specific application at hand. It is possible to calibrate a hydrophone and recording system with an overall uncertainty of better than 1 dB (expressed at a 95 % confidence level). It is recommended that a full laboratory calibration is undertaken before and after every major deployment or sea-trial (IEC 60565 2006, ANSI S1.20 2012).

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 and the recordings produced by the system are analysed. For calibration of individual components, the hydrophone is calibrated separately by an acoustic measurement, but the other components are calibrated using known electrical input signals. The components that require calibration are:

#### Hydrophone

There are national and international standards describing the calibration of hydrophones such as IEC 60565:2006 – The calibration of hydrophones in the range 0.001 Hz to 1 MHz (available in the UK as BS60565:2007), or ANSI S1.20-2012 - Procedures for calibration of underwater electro-acoustic transducers. The calibration should conform to these procedures and be traceable to national or international standards maintained at a national metrology institute. Hydrophone calibration data is typically expressed in  $\mu\text{V}/\text{Pa}$ , or in decibels as dB re 1 V/ $\mu\text{Pa}$ . Typically, it is expressed at a succession of discrete frequencies, or in the form of a calibration curve.

Note that at frequencies well below the resonance frequency, the hydrophone sensitivity should be invariant with frequency. However, as a hydrophone approaches its resonance frequency, the sensitivity cannot be considered to be “flat” and is likely to show variations in response. If the recorded data is already processed into third-octave bands before the correction for hydrophone sensitivity is applied, the required calibration values are the mean sensitivities for each of the frequency bands. Where the hydrophone sensitivity is not flat, a constant value across the band cannot be assumed. Note that if the hydrophone is placed close to a reflective boundary (such as a recorder case), interference from reflected signals will cause further fluctuations in the sensitivity with frequency at kilohertz frequencies.

Note that it is advisable to “wet” a hydrophone before deployment by cleaning the surface with a mild detergent. This will ensure that the surface is free of grease and dirt, and prevent air bubbles from adhering to the surface and causing distortion of the measured signal.

Note also that if extra cable is added to a hydrophone, this will reduce the overall sensitivity. This is the case for hydrophones without an integral preamplifier. For hydrophones that have an integral preamplifier within the hydrophone body, adding extension cable will not affect the sensitivity.

Note that, for some hydrophones, the response may show a dependence on the water temperature and depth of immersion [Beamiss et al 2002]. If the conditions for the calibration are significantly different from those during its use in the field, this may add uncertainty to the measurement. If there is evidence that the hydrophone performance varies significantly with temperature/depth, the calibration should be undertaken as close to the applicable conditions as possible. Alternatively, a hydrophone should be chosen which has a stable performance with temperature/depth (as far as possible).

Advice on choice and use of hydrophones, including the wetting of hydrophones, how to correct for added extension cable, and the performance as a function of depth and temperature, can be found at: <http://www.npl.co.uk/acoustics/underwater-acoustics/>.

#### Amplifiers

The performance is typically expressed as a gain factor, either in terms of a linear gain (e.g. x10) or in decibels (e.g. 20 dB). Note that the amplifier gain may not be invariant with frequency, particularly at the extremes of the operating frequency band.

#### Filters

The filter performance is typically expressed as an insertion loss factor, either as a linear factor or in decibels. 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: (i) 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); (ii) 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); (iii) 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 may need to be known to correct the data before analysis.

#### Analogue to Digital Converter (ADC)

The range setting (full-scale) and the calibration factor of the ADC must be known. Typically, this calibration factor will 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.

### **In-situ calibration checks and Quality Assurance**

It is advisable to undertake in-situ checks on the system calibration just before and after deployment, and in between any repeated deployments. To do this, it is advisable to make use of a hydrophone-calibrator, which provides the hydrophone with a signal of known amplitude at a single-frequency (commercial devices are available which commonly operate at 250 Hz). The calibrator typically consists of an air-pistonphone that generates a known sound pressure level inside a small coupler into which the hydrophone is inserted. The sound pressure depends on



the free-volume inside the coupler when the hydrophone is inserted, and so the coupler must be calibrated for each type of hydrophone that is used with that coupler.

Although the hydrophone calibrator provides a check at only one frequency, it does allow the entire system to be checked using an acoustic stimulus. It is also possible to undertake electrical check calibration of the system components. If the hydrophone in use has an insert voltage capability (many commercial hydrophones with integral preamplifiers have this facility), this may be used to check the electrical integrity and perform a calibration by electrical signal injection. This is a useful technique when deploying long cabled systems from vessels, and can be performed without retrieving the hydrophones. However, the method does not perform an acoustical check on the hydrophone element.

### 3.5.4 Deployment

#### Deployment method

The main aims of the deployment configuration are to:

- sample the sound field at an appropriate point in the water column for the duration and range of conditions required for the application;
- minimise parasitic sources of non-acoustic signals caused by the presence of the hydrophone and its platform, which contaminate the measurements and lead to spurious data.

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 of such a system will require either an acoustic release system or a surface buoy deployed from a seabed anchor.

Another factor when choosing final positions for deployment is the likely damage or loss of the equipment (and data). This is a problem for long-term deployments using autonomous systems. The main dangers are from (i) extreme weather; and (ii) fishing activity.

#### Deployment related noise

In addition to the self-noise of the measuring system described in Section 2.10.4.2, 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 signals [Cato 2008, Harland 2008, ANSI S12.64: 2009, Dudzinski *et al.*, 2011].

The following list shows some of the more common sources of unwanted 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 these generate signals of frequency less than 100 Hz). Methods of reducing flow induced noise include locating the hydrophone close to the seabed where flow is reduced, use of a “sonar-dome”, use of drifting buoys, and the use of mechanical fairings, often in spiral or helical form around cables and housings (Urlick 1983, Ross 1987, Cato 2008). For autonomous recorders where the hydrophone is protruding from the recorder body, the problem can be exacerbated by turbulent flow around the end of the recorder casing. Strong fluid flow can also cause vibration of moorings and excite resonances in the recorder body. It is not always easy to check for the presence of flow-induced noise, but the recorded signals at low frequencies (<100 Hz) should be checked for correlations with tidal information – the flow noise signal will often show the same cyclic variations as the tides. If measurements have been made at both slack tide and at full tidal flow, it may be possible to quantify the effect of flow noise by comparison of the data.

#### 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 (e.g. elastic rope), and the use of cable fairings will help to minimise the problem (Urlick 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.



### 3.5.5 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 (this can be measured using an echo sounder)
- Water temperature and air temperature
- Hydrophone depth in the water column
- GPS locations of sources, hydrophones and recording systems
- Seabed type
- Profile of conductivity, temperature and hydrostatic pressure as a function of depth in the water column using a CTD probe - from this information the salinity, density and sound speed profiles can be calculated from standard equations - alternatively, the sound speed profile can be measured directly using a velocimeter
- The pH of the seawater by use of a pH meter - an estimate of pH could be required for calculation of the absorption coefficient
- A monitor of the presence of vessels in the area where measurements are being made using a receiver of ship traffic Automatic Identification System (AIS)
- Nearby ship wrecks
- Nearby military restricted area
- Nearest oceanographic survey station
- Nearest marine reserve area
- Other permanent anthropogenic noise sources (gas pipe line, wind farm, etc.).

### 3.5.6 Averaging method (M2-b)

In Part III, chapter 2.8 the pros and cons of different kinds of averaging are outlined. Indicator 2 is specified by the Commission Decision of Sep 2010 as: *“Trends in the ambient noise level ... (... average noise level ... over a year)”*, which was interpreted by the TSG Noise as: *“Trends in the annual average of the squared sound pressure associated with ambient noise ... expressed as a level in decibels”* [Van der Graaf *et al.*, 2012].

In chapter 2.8 the earlier definition was evaluated, by comparing the annual average (arithmetic mean) of the squared sound pressure with other possible metrics. The following four averaging methods for this distribution were considered:

- Arithmetic mean (AM) of snapshots of mean square sound pressure (the TSG Noise interpretation)
- Geometric mean (GM) of the same snapshots (equivalent to arithmetic mean in decibels)
- Median of the same snapshots
- Mode of the same snapshots

The purpose of Indicator 2 is to quantify noise within a frequency range, likely to be influenced by shipping. Shipping noise has both permanent and intermittent components, and an annual average will automatically include both. Normally, on a year-round basis there are no anthropogenic underwater sounds more persistent than shipping, but there may be some locations at which shipping noise is not the largest contributor to anthropogenic ambient sound, within the frequency bands relevant to Indicator 2.

The different averaging methods were evaluated against the following criteria, where the method needed to be:

- Robust to minor changes or differences in implementation.
- Representative of a large enough region to justify its use as an indicator of GES.
- Practical (simple to implement).
- Compatible with comparable regulations or procedures (desirable but not essential).

Based on analysis of available data the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO), it was concluded that the arithmetic mean will initially be the best option. TSG Noise advises MS to adopt the arithmetic mean. The main considerations in reaching this recommendation are:

- a) the arithmetic mean includes all sounds, so there is no risk of neglecting important ones
- b) the arithmetic mean is independent of snapshot duration

The trend is the trend in the arithmetic mean. In order to establish the statistical significance of this trend, additional statistical information about the distribution is necessary. For further details, see Part III of the Monitoring Guidance. TSG Noise recommends that the complete distribution be retained for this purpose, in bins of 1 dB.

When an average value for ambient noise is established using the arithmetic mean, the value found for the average will be dominated by the noisiest contribution. Therefore, monitoring in the vicinity of high shipping density areas, the arithmetic mean is likely to be dominated by this contribution.

### **3.5.7 Standards and definitions for appropriate noise monitoring models**

The modelling approach should take into account representative environmental conditions (oceanography, sea state, sea bed, etc.). The results provided by the modelling should be consistent with the averaging methods applied to the measurements. Optionally, the modelling could be done in such a way as to make percentile calculation of received level possible at the scale of individual points and of a region or a basin, should MS require such assessments.

Modelling and input knowledge is likely to improve with the development of new technologies and techniques (operational oceanography, noise from ships, calculation performances, etc.).

If Member States wish to compare calculated historical trends with new predictions, modelling output should include an evaluation of its sensitivity to modelling inputs (environmental data, anthropogenic data, etc.) and inherent uncertainties.

### **3.5.8 Examples of appropriate modelling approaches**

The physics of underwater sound propagation are generally well understood. The propagation of sound through water is described by (the wave) or Helmholtz equation, with appropriate boundary conditions. A number of models have been developed to simplify propagation calculations. These models include “ray theory”, normal mode solutions, and parabolic equation

simplifications to the wave equation [Jensen *et al.*, 1994]. Each set of solutions is valid and computationally efficient within limited frequency and range, and may involve other limits. Ray theory is more appropriate at short range and high frequencies, while the other solutions function better at long range and low frequency. [Harrison 1989]. Modelling appropriate for some specific sounds and conditions is still being developed [Reinhal and Dahl 2011, Zampolli *et al.*, 2013], e.g. the propagation of loud impulsive sounds (from piling, or explosives) in shallow water.

Of the methods described by [Jensen *et al.*, 1994], the most practical are parabolic equation, normal modes and ray theory. A practical method, not described in Jensen's book, is Weston's flux integral method [Weston 1959]. This method can be applied to arbitrary seabed bathymetry [Weston 1976] and has recently been extended to include convergence effects for arbitrary sound speed profiles [Harrison, 2013].

Examples of appropriate modelling approaches can be found on open access websites, such as the Ocean Acoustics library, that contain acoustic modelling software and data. It is supported by the U.S. Office of Naval Research (Ocean Acoustics Program) as a means of publishing software for general use to the international ocean acoustics community (see <http://oalib.hlsresearch.com/>). Also, the AcTUP propagation modelling software is available from the Centre for Marine Science and Technology of Curtin University (see <http://cmst.curtin.edu.au/products/actoolbox.cfm>).

Examples of basic information needed as input parameters for modelling are also available. For data on large and many small ship movements the Automatic Identification Systems (AIS) can be used, since all large merchant vessels are required to carry an AIS-transponder on board (see <http://www.marinetraffic.com/ais/>).

In present European noise modelling and mapping projects (as described in part III chapters 2.3-2.6) ships are characterised in terms of the source level of an equivalent monopole, at a specified depth. TSG Noise advises the continued use of this approach. See [de Jong *et al.*, 2012] for a definition of monopole source level for the equivalent point source. See [Wales & Heitmeyer 2002] for typical values of commercial shipping source levels. Many publications on radiated noise for ships, including the ANSI Standard S12.64-2009 [ANSI, 2009] do not report the source level, but the radiated noise level, while still referring to this as "source level".

TSG Noise concludes that further investigation into best practice, or even standardised methods, is needed. In addition to data describing the source factors that influence propagation bathymetry, sound velocity profiles are also needed. Of particular importance in deep water is the sound speed profile, available in the World Ocean Atlas 2009, (see [http://www.nodc.noaa.gov/OC5/WOA09/pr\\_woa09.html](http://www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html)); and absorption of sound in seawater, described on the website of the National Physical Laboratory (NPL) in the UK (see <http://resource.npl.co.uk/acoustics/techguides/seaabsorption/>). Some other parameters may be found: global bathymetry (of particular importance in shallow water is the bathymetry <http://www.ngdc.noaa.gov/mgg/global/>; (1 arc minute), <http://www.gebco.net/>; or [http://gcmd.nasa.gov/records/GCMD\\_DBDBV.html](http://gcmd.nasa.gov/records/GCMD_DBDBV.html)); and sediment composition, often available from geophysical surveys).

For low frequency shipping noise (up to about 100 Hz), the sea surface can be designated as a perfect reflector, with a 180 degree phase change (a so-called "pressure release" surface). For higher frequencies, especially above 1 kHz, a better description is probably needed [Ainslie 2010, Ch 8, pp 362-369]. The NPL website also contains useful information and equations for calculating the speed of sound in sea-water, as a function of temperature, salinity and pressure (or depth) (<http://resource.npl.co.uk/acoustics/techguides/soundseawater/>).

A recent modelling approach used to make sound maps is described in the Irish STRIVE Noise report, issued in May 2013.

## 4. MAIN CONCLUSIONS AND RECOMMENDATIONS

### 4.1 Monitoring impulsive noise

The initial purpose of monitoring impulsive noise is to assess the pressure on the environment, by making available an overview of all loud impulsive low and mid-frequency sound sources, through the year and throughout regional seas. This will enable MS to get an overview of the overall pressure on the environment from these sources.

TSG Noise recommends monitoring of indicator 11.1.1 by **setting up a register of the occurrence of these impulsive sounds**. This is the first step to establish the current level and trend in these impulsive sounds.

Airguns, pile-driving, explosives, and sonar working at relevant frequencies and some acoustic deterrent devices are the **most important sound-sources that should be considered for inclusion in the register**. Additional sources that could also be of concern include boomers, sparkers and scientific echo sounders. TSG Noise proposes to use thresholds for uptake in the register. Thresholds were derived that will ensure that all sources that have a potential for significant population level effect will be included in the register. However, the use of these (relatively low) thresholds will result in sources with a relatively low potential for significant impact also being registered. TSG Noise concluded that there is a need for more detail in the register than just the day and location; of this additional information, the source level is the most important. The initial purpose of monitoring impulsive noise is to assess the pressure on the environment, by making available an overview of all loud impulsive low and mid-frequency sound sources, through the year and throughout regional seas. This will enable MS to get an overview of the overall pressure on the environment from these sources.

The **information required** to derive pulse-block days (the number of days that a certain threshold (pulse) is exceeded in an area (block)), are:

- Position data (geographic position (lat/long), licensing block/area)
- Date of operation
- Source properties:
  - Essential (minimum)
    - Source level or proxy;

Additional data about source properties that could be recorded, when available, include source spectra, duty cycle, duration of transmissions (and actual time/time period), directivity, source depth and platform speed. Collection of this data would enable improved assessment of the overall pressure on the environment.

The **main aim of the registry** is to provide an overview of all loud sounds. If the registry leaves out certain sound sources it would not fulfil the aim of addressing cumulative effects of impulsive noise; it is therefore recommended that information on all sources should be included [see Van der Graaf *et al.*, 2012]. TSG Noise therefore suggest that data on explosives and military activities (of which the sole purpose is defence or national security) should also be included in the register, but notes that this should be on a voluntary basis as this is a national policy issue.

TSG recommends that a **joint register of the occurrence of these impulsive sounds should be set up at least on a Regional Sea level**, the format of which must ensure future

compatibility. This cannot be conclusively decided until the register location and management are decided, but there are some factors that could be agreed upon, such as:

- ✓ Use of a common language (English)
- ✓ Use of a common format for date in accordance with the appropriate standard (ISO 8601) (YYYY-MM-DD or YYYYMMDD)
- ✓ Use of a common format for position (latitude and longitude, decimal degrees)
- ✓ Use of a common map projection (unprojected data – WGS84)
- ✓ Use of a common template (i.e. setting out the order in which information is recorded)

The register can be used to estimate **the spatial and temporal impact on the environment** (the total period and total habitat loss by impulsive noise sources) and for determining the **baseline level**. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists. Once a baseline and targets have been set, the register can be used for management purposes (e.g. regulating planning and licensing activities) and to assist in marine spatial planning, incorporating displacement mitigation guidelines and reducing the potential for cumulative impacts.

## 4.2 Monitoring ambient noise

TSG Noise concludes that the **combined use of measurements and models** (and possibly sound maps) is the best way for Member States to ascertain levels and trends of ambient noise in the relevant frequency bands. Member States should be careful to balance modelling with appropriate measurements. This report provides concrete advice on specifications for noise monitoring systems, noting that there are no international standards for monitoring underwater ambient noise, for modelling and for data storage. TSG Noise concludes that such standards are needed. **TSG Noise therefore recommends that international standards be developed for the measurement, modelling and data storage of ambient noise** with application to underwater noise monitoring, including the measurement of radiated sound from important sources such as airgun arrays and underwater explosions (standards for the measurement of radiated sound from ships and impact pile driving are already under development by ISO).

Monitoring indicator 11.2.1 will enable MS to quantify the environmental pressure (expressed as ambient noise level) as well as trends in ambient noise levels within the two frequency bands. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists. Since there is very little information available on the effects of increased ambient noise level, TSG Noise cannot give concrete advice on interpretation of results at this stage.

In addition to the advice needed to develop and deploy the systems needed to monitor the indicator, TSG Noise concluded that **trends only will not be sufficient to describe GES. To describe GES levels**, based on a wider overview of the area, a combination of modelling / measurements and possible mapping will be needed. Next to that, much greater **understanding of the relationship between the environmental pressure caused by ambient noise and the state of the ecosystem is needed before GES can be understood**.

There is no requirement for Member States to describe the complete noise field in their waters, a limited number of monitoring stations (measurement locations) would suffice. However TSG Noise concluded that the **use of models can contribute directly to effective ambient noise monitoring and assessment**.

TSG Noise has not defined exact locations for deploying equipment necessary to monitor relevant frequency bands of ambient noise. However, TSG Noise advises **Member States within**

**a sub region to work together to establish an ambient noise monitoring system**, and TSG Noise has provided a set of rules for the design of a monitoring strategy. Furthermore, TSG has provided **guidance for reporting results**.

The advantages and disadvantages of different averaging methods (arithmetic mean, geometric mean, median and mode) are reviewed, and TSG Noise **recommends that Member States adopt the arithmetic mean**.

In order to establish the statistical significance of the trend, additional statistical information about the distribution is necessary. TSG Noise recommends that **complete distribution be retained in the form of sound pressure levels as a function of time, along with a specified averaging time**. TSG Noise advises the retention of the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration. TSG Noise advises MS that the snapshot duration should not exceed one minute.

Additional and background information is provided in **Part III of the Monitoring Guidance** that includes further information, substantiation and detailed references.



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Abstract

This document has been prepared by the Technical Subgroup on Underwater Noise and other forms of Energy (TSG Noise), established in 2010 by the Marine Directors, i.e. the representatives of directorates or units in European Union Member States, Acceding Countries, Candidate Countries and EFTA Member States dealing with or responsible for marine issues. In December 2011, the Marine Directors requested the TSG Noise to provide monitoring guidance that could be used by Member States in establishing monitoring schemes to meet the needs of the Marine Strategy Framework Directive indicators for underwater noise in their marine waters. This document presents the recommendations and information needed to commence the monitoring required for underwater noise.

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JRC SCIENTIFIC AND POLICY REPORTS

# Monitoring Guidance for Underwater Noise in European Seas

## Part III: Background Information and Annexes

*A guidance document within the  
Common Implementation  
Strategy for the Marine  
Strategy Framework Directive*

MSFD Technical Subgroup on  
Underwater Noise

2014



Report EUR 26556 EN



European Commission  
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## SUMMARY

The Marine Strategy Framework Directive (MSFD) requires European Member States (MS) to develop strategies for their marine waters that should lead to programmes of measures that achieve or maintain Good Environmental Status (GES) in European Seas. As an essential step in reaching good environmental status, MS should establish monitoring programmes enabling the state of the marine waters concerned to be assessed on a regular basis. Criteria and methodological standards on GES of marine waters were published in 2010 (Commission Decision 2010/477/EU). Two indicators were described for Descriptor 11 (Noise/Energy): 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 Subgroup (TSG) for further development of Descriptor 11 Noise/Energy. TSG (Underwater) Noise in 2011 focused on clarifying the purpose, use and limitation of the indicators and described methodology that would be unambiguous, effective and practicable; the first report [Van der Graaf et al., 2012] was delivered in February 2012. Significant progress was made in the interpretation and practical implementation of the two indicators, and most ambiguities were solved.

In December 2011, EU Marine Directors requested the continuation of TSG Noise, and the group was tasked with recommending how MS might best make the indicators of the Commission Decision operational. TSG Noise was asked first to provide monitoring guidance that could be used by MS in establishing monitoring schemes for underwater noise in their marine waters. Further work includes providing suggestions for (future) target setting; for addressing the biological impacts of anthropogenic underwater noise and to evaluate new information on the effects of sound on marine biota with a view to considering indicators of noise effects.

The present document is **Part III** of the **Monitoring Guidance for Underwater Noise in European Seas** and provides MS with the background information, examples and references needed to commence the monitoring required to implement this aspect of MSFD. TSG Noise has focussed on ambiguities, uncertainties and other shortcomings that may hinder monitoring initiatives and has provided solutions, and describes methodology for monitoring both impulsive and ambient noise in such a way that information needed for management and policy can be collected in a cost-effective way. TSG Noise has no doubt that further detailed issues will arise once monitoring starts, but hopes the principles laid out in this guidance will help resolve these.

The Monitoring Guidance for Underwater Noise is structured, as follows:

- Part I: Executive Summary & Recommendations,
- Part II: Monitoring Guidance Specification, and
- **Part III: Background Information and Annexes.**

Part I of the Monitoring Guidance is the executive summary for policy and decision makers responsible for the adoption and implementation of MSFD at national level. It provides the key conclusions and recommendations presented in Part II that support the practical guidance for MS and will, enable assessment of the current level of underwater noise.

Part II, is the main report of the Monitoring Guidance. It provides specifications for the monitoring of underwater noise, with dedicated sections on impulsive noise (Criterion 11.1 of the Commission Decision) and ambient noise (Criterion 11.2 of the Commission Decision) designed for those responsible for implementation of noise monitoring/modelling, and noise registration.

Part III, the background information and annexes, is not part of the guidance, but is added for additional information, examples and references that support the Monitoring Guidance specifications.

## **1. Introduction**

This document Part III presents the background information, examples, the annexes, including references and glossary and is added for additional information, examples and references that supported the Monitoring Guidance.

In the following chapters, contributions from various authors in the form of short articles are presented. These deal with various relevant topics and examples of scientific substantiation and project-related information that provide additional insight that support the recommendations of TSG Noise provided in the Monitoring Guidance.

## 2. Background information and further substantiation

### 2.1 Guidance on underwater sound sources to be included in the Register of Low and Medium Frequency Sources of Impulsive Sound

(Authors: M.A. Ainslie & R.P.A. Dekeling)

#### Summary

The purpose of this section is to substantiate the advice of TSG Noise to MS on the choice of thresholds of source level and proxies for inclusion in the Noise Register associated with the implementation of Indicator 11.1.1. Our first step is to choose a relevant metric for «significant impact». The value of source level then follows from the choice of distance for potentially significant impact and of propagation model used to convert from that distance to a source level. Conversion to a suitable proxy is necessary for those sources for which source level is not an appropriate measure.

For the most relevant sources of low and mid-frequency impulsive noise minimum thresholds for uptake in the register are derived. Technical Sub-group Underwater Noise (TSG Noise) concludes that for pile-drivers no minimum threshold should be used and that all pile-driving activities should be registered. For sonars, airguns, acoustic deterrents<sup>1</sup> and explosions, minimum thresholds can be used and values for these minimum thresholds are recommended.

TSG Noise concludes that it is useful to distinguish between sources of different level. To register detailed information on levels will be too complicated or may hamper information gathering. A compromise is offered, suggesting source level data collection in 10 dB bins.

#### 2.1.1 Introduction

The Commission Decision of September 2010 requires EU Member States (MS) to address anthropogenic sound sources that may result in significant impact, via Indicator 11.1.1 of GES (henceforth abbreviated as “Indicator 1”). MS will need to collect data on loud low- and mid-frequency impulsive sound sources, and the first TSG Noise report, in line with the earlier TG11 report [Tasker *et al.*, 2010], proposes to achieve this by establishing a register of the occurrence of these sources. The next work item for TSG Noise was to establish a monitoring guidance, giving concrete guidance which sources should be taken up in the register and how the data should be collected. While working on its first report, TSG Noise attempted to distinguish between sound sources that may entail significant impact and sources that were not, as a selection criterion to decide whether sources should be taken up in the register, but this could not be completed in the time available in 2011.

At the TSG Noise meeting of April 2012 in Spain, this issue was discussed and TSG Noise concluded that some adaptation to the earlier approach (which was based on the text of the Commission Decision) was needed. In the Spain meeting TSG Noise concluded that:

- Given uncertain knowledge of which sources cause significant impact, it is helpful to distinguish between a threshold for inclusion in the source register (henceforth, “the Register”) and the threshold that may cause significant impact, i.e. uptake in the Register does not necessarily need

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<sup>1</sup> The term “acoustic deterrents” is a general term to indicate acoustic sources use primary purpose is to deter an animal from approaching an area, regardless of the reason for doing so, and regardless of source level. It includes devices commonly known as “acoustic harassment devices” (abbreviated “AHD”) as well as “acoustic deterrent devices” (abbreviated “ADD”).



to mean that the source is actually causing ‘significant’ impact; we do not yet fully know when a loud source causes ‘significant’ impact.

- We propose to adopt a lower threshold for the Register than for Indicator 1. Doing so enables us to deal with this uncertainty by choosing a deliberately low threshold for the Register; thus, the Register would only exclude sources unlikely to have significant impact, resulting in a lower threshold for inclusion than including those that are likely to have significant impact.
- The Register will include quantitative information about the sources; TSG Noise will advise what extra information (e.g., source level, frequency of use, directivity index) is needed in the register.
- Registration in decibel bins (e.g., 10 dB (equivalent)).

The initial purpose of this indicator is to assess the pressures on the marine environment, 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 on the environment from these sources, which has not been achieved previously (see the 1<sup>st</sup> TSG report [Van der Graaf et al., 2012].).

To achieve this target, we should make sure that we register all relevant sources to assess the pressure on the environment. At the same time, it should be ensured that registration efforts are not wasted on low energy sources that are probably insignificant. Because we cannot at this time determine when sources are significant, we will register all sources that have the potential for significant impact from an ecological perspective (population or local population level). We are not saying that no animals are adversely affected by omitted sources; only that any effect is not considered significant at the population or local population level. This means that at this stage we will only exclude the sources that are less likely to have significant impact from this ecological perspective. For the sources that we will register the data will be collected in bins to be able to differentiate between very loud sources and sources that might only have limited impact.

In this chapter the rationale to decide whether a sound source needs to be taken up in the register is explained:

- The register should be workable, and preferably based on information already available.
- The register needs to ensure that all relevant sound sources of concern will be included.
- Registering of sound sources that are less likely to be of relevance should be avoided.

This chapter addresses the last issue, and describes a methodology for determining which sources are less likely to result in significant impact and that may be excluded from registration. It does so by first describing “significant impact” and the relation between received levels and effect. By first making a precautionary choice for the relevant parameters (received levels) and describing received levels and propagation loss, we can get insight into the source levels needed for a likely effect, depending on the type of source and how the source is used. As a final step, for cases where the source level is difficult to obtain, the source level is converted to a more convenient proxy.

### TERMINOLOGY AND DECIBEL REFERENCE VALUES

The terminology in this document follows the recommendations from the international workshop on acoustic standards that was held in Delft, The Netherlands, in February 2011, as described in a consensus report for the Dutch government [Ainslie (Ed.), 2011]; in this meeting consensus was reached on the definitions contained in that document making a suitable starting point from which to construct an international standard.

The consensus report provides for a choice between three alternative conventions for reference values associated with levels cited in decibels:

- The ‘10lgP rule’, by which the reference values are proportional to power ( $1 \mu\text{Pa}^2$  for SPL and  $1 \mu\text{Pa}^2 \text{ s}$  for SEL).
- The ‘20lgA rule’, by which the reference values are proportional to the square root of power ( $1 \mu\text{Pa}$  and  $1 \mu\text{Pa s}^{1/2}$ ); and,
- A third, mixed rule, by which a choice is made between power and root power on a case by case basis, according to the perceived convention.

This report follows the mixed rule, with the 20lgA convention for some quantities (e.g., 1  $\mu\text{Pa}$  for SPL and 1  $\mu\text{Pa m}$  for source level)<sup>2</sup> and the 10lgP convention for others (e.g., 1  $\mu\text{Pa}^2 \text{ s}$  for SEL and 1  $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$  for energy source level).

### WHAT IS MEANT BY ‘SIGNIFICANT IMPACT’?

In the first report of TSG Noise [Van der Graaf *et al.*, 2012] it was explained that the indicator for impulsive noise would address ‘displacement’, i.e. ‘severe and/or sustained and/or long-term avoidance of an area’. In the methodology described below thresholds at which this effect was found in marine animals are used. Most of the available data about effects of sound on the marine environment describes effects on marine mammals; these animals are dependent on using sound, and many species of marine mammals are known to be sensitive to sound. Therefore, for determination of thresholds, TSG Noise used data on the response thresholds of marine mammals, but this does not exclude the possibility that species from another group/family would show responses at lower levels. TSG Noise also realises that there are also observations of impact on fish from airguns and pile driving where the fish has undertaken both severe and/or sustained displacements and that displacement can include vertical migrations.

### SOUND PRESSURE LEVEL OR SOUND EXPOSURE LEVEL?

An evaluation of possible metrics that is most appropriate for assessment of behavioural effect can be found in [Southall *et al.*, 2007]. In this landmark publication it was suggested that sound pressure levels were the best available metric for assessing behavioural effects:

*Considering all of these limitations and the nature of the available data, as a practical matter, we use [sound pressure level (SPL)] as the acoustic metric for the behavioral analyses given below. Where necessary and appropriate, simple assumptions regarding transmission loss were applied to predict [received levels]. This was done only for studies that provided sufficient information on source and environmental characteristics. Our approach does not presume that SPL is necessarily the acoustic metric best correlated with behavioral changes (significant or otherwise). In particular, SPL fails to account for the duration of exposure whereas this is captured using [sound exposure level]. SPL is the metric that has most often been measured or estimated during disturbance studies, however. Thus, it is currently the best metric with which to assess the available behavioral response data.*

For the scope of this document (excluding the insignificant sources) we adopt this approach, although TSG Noise notes that SPL may not be the applicable metric for assessing/ understanding behavioural effects in fish. When using SPL we do not consider the accumulated received SEL over the animal’s full duration of exposure but only the actual, often highest, experienced level of sounds. For some types of sound the SPL is not the most practical metric. For these cases, we will use a different approach and prefer single pulse SEL (as opposed to cumulative SEL) to SPL. This approach applies for sounds with an explicitly impulsive character, these sounds were called ‘pulses’ by Southall *et al.* [2007] (brief, broadband, atonal, transients which are characterized by a relatively rapid rise-time to maximum sound pressure amplitude followed by a decay that may include a period of diminishing and oscillating maximal compressional and rarefactional pressures). Examples of pulses are sounds from explosions, gunshots, sonic booms, seismic airgun pulses, and pile driving strikes; see Southall *et al.* [2007]. Furthermore, single pulse SEL is proposed by Southall as a metric for behavioural response to single pulses.

The reason for this approach is that for short pulses, changes in the shape of the pulse can occur over time (e.g., due to multipath propagation) so that care is needed in the interpretation of reported SPL or zero to peak sound pressure values. For this reason, the (single pulse) source energy (characterized by the energy source level  $SL_E$ ; [Ainslie, 2010]), which is not affected by changes in pulse shape, is a more robust

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<sup>2</sup> The reference value “1  $\mu\text{Pa}$  @ 1 m”, though widely used, is avoided here because 1  $\mu\text{Pa}$  @ 1 m is not an SI unit. The intended meaning is the same.

measure than zero to peak, peak to peak or RMS sound pressure for the characterization of short pulses and *single-pulse* SEL is a more practical measure for reporting the received levels. (See Ainslie, 2010, ch 10, page 525).

### WEIGHTED OR UNWEIGHTED?

For the purpose of a criterion for inclusion in the Register, unweighted levels are preferred to weighted ones. This is done for simplicity, avoiding the complication of which weighting to use. Weighting can be applied in a later process and might require different weighting functions based on which functional hearing group of animals is considered. Therefore, including unweighted levels in the Register allows for different types of analysis on a later phase.

### SOURCE LEVEL OR OTHER SOURCE PARAMETERS?

Until now the TSG has worked towards source level (SL) and this report continues in this direction. For some types of sources, SL is unsuitable either because the source cannot be characterised in terms of SL or because it is not usual to do so, and for such sources TSG Noise advises converting the appropriate source level threshold into a threshold for a suitable proxy. One example is for a pile driver, for which the report of the February 2011 international workshop concludes that no definition is available [Ainslie (Ed.), 2011]. For other sources (e.g., explosives) even though an (energy) source level is sometimes used (and well defined in deep water at least, at long distances from the source), we advise use of a proxy in terms of equivalent TNT charge mass in order to eliminate the need for the conversion of this charge mass to a source level. Specific proxies advised are the equivalent TNT charges mass of explosives, the hammer energy of an impact pile driver and the source level of an airgun array.

## 2.1.2 Choice of SEL or SPL threshold for inclusion in the Register

### MULTIPLE EXPLICITLY IMPULSIVE SOUNDS (SEL THRESHOLD FOR "SOUTHALL *ET AL.* PULSES")

We have made a brief summary of the scarce information currently available concerning displacement, this was also described in the 1<sup>st</sup> TSG Noise report.

Danish work [Tougaard *et al.*, 2012] mentions ‘received levels of sound were, on average, 140 dB re 1 $\mu$ Pa (peak-peak) at’ the distance within which harbour porpoises<sup>3</sup> were observed to avoid impulsive sounds from a pile driver. This is expressed in terms of peak-to-peak sound pressure, which makes it difficult to use within the present framework.

Some work has been done in Germany at the “alpha ventus” wind park. Some of this has been published in a report by Wittekind *et al.* [2010] (*Auswirkungen des Baus des Offshore-Testfelds „alpha ventus“ auf marine Säugetiere*). This publication reports that porpoises react to sound for a single pulse with SEL = 140 dB re 1  $\mu$ Pa<sup>2</sup> s or higher.

Use is made of these values from field data in preference to data available from laboratory work or otherwise artificially constrained situations: e.g. Lucke made TTS-measurements of harbour porpoises after exposure to airgun sounds [Lucke *et al.*, 2009]. In this work consistent “aversive behaviour” was noted when single-pulse SEL-values exceeded 145 dB re 1  $\mu$ Pa<sup>2</sup> s; Kastelein observed behavioural changes at lower values (single pulse SEL of 115 dB re 1  $\mu$ Pa<sup>2</sup> s) [Kastelein *et al.*, 2011], but in an artificial setting with very low background noise levels (see e.g. Ellison *et al.*, [2011] for considerations on background noise levels).

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<sup>3</sup> The harbour porpoise is known to be one of the most sensitive marine animal species, for both physical and behavioural effects. For this reason this species has been selected in this approach, implying use of a low limit and hence a conservative approach [Southall *et al.*, 2007; Lucke *et al.*, 2009; Kastelein, 2011].

The term ‘explicitly impulsive sound’ is used in this report as a synonym of a ‘pulse’ in the sense of Southall *et al* (2007).

Therefore we propose  $SEL_0 = 140 \text{ dB re } 1 \mu\text{Pa}^2 \text{ s}$  as a threshold for significant behavioural disturbance due to multiple explicitly impulsive sounds.

#### **SINGLE EXPLICITLY IMPULSIVE SOUNDS (SEL THRESHOLD FOR A SINGLE "SOUTHALL *ET AL.* PULSE", SUCH AS AN EXPLOSION)**

For most of the activities generating impulsive sounds considered to have effect on animals (piling, sonar, seismic) the sounds will be transmitted repeatedly for longer durations (e.g. piling for a wind turbine, a sonar exercise or a complete seismic survey) and exposure to these repeated impulsive sounds induces the reaction. Explosions, and certainly most of the large explosions, are often not repeated events: in NW-Europe, the most relevant activity is clearing of unexploded legacy ammunition, demolition of oil extracting constructions and within geological research. Most studies on the effect of explosions focus on physiological damage to marine life, and not on behavioural effects. However, for this specific type of sound, Southall *et al.* [2007] also suggested that these should be treated separately and suggested to use higher thresholds for behavioural effects; Southall *et al.* [2007] proposed the TTS-value as threshold for behavioural impact of marine mammals. It is not known to the present authors whether animal displacement is a relevant effect of these single impulsive sounds. Nevertheless it is considered desirable to keep sources of single "Southall *et al.* pulses" (like explosions associated with the detonation of individual mines) in the Register, and we follow this proposal of Southall *et al.* [2007] which means that the threshold for a single pulse is higher than that for multiple pulses. While for multiple explosions in a short time period (e.g. a military exercise or research campaign) the lower threshold for multiple explicitly impulsive sounds could be used, doing so would only make a difference for multiple explosions of mass less than 8 g, which are infrequent events. For this reason, TSG Noise recommends a threshold for inclusion of that is based on single explosions, irrespective of whether the actual event to be registered involves single or multiple explosions.

For the single pulse event we propose to use the TTS-onset values found by Lucke as threshold  $SEL_0 = SEL_{TTS} = 164.3 \text{ dB re } 1 \mu\text{Pa}^2 \text{ s}$  from [Lucke *et al.*, 2009] as a threshold for significant behavioural disturbance due to single explicitly impulsive sounds.

#### **NON-PULSE SOUNDS, INCLUDING SONAR (SPL THRESHOLD FOR "SOUTHALL *ET AL.* [2007] NON-PULSES")**

There are a number of research programmes addressing the effect of sonar on cetaceans and the knowledge is growing rapidly, and by now there are some (peer-reviewed) publications on the behavioural effects of sonar on cetaceans.

In this approach we decided to make use of the most recent publications available, firstly the study on the effect of sonar on beaked whales [Tyack *et al.*, 2011]. In this publication a value for interruption of echo location behaviour at  $SPL = 140 \text{ dB re } 1 \mu\text{Pa}$  for beaked whale exposure to mid-frequency sounds is suggested.<sup>4</sup> However, recently it was suggested that at lower levels, from 120-130 dB re 1  $\mu\text{Pa}$ , there was an increased risk of severe behavioural responses, although there are large differences across species - long-finned pilot whales showing little response below 150 dB re 1  $\mu\text{Pa}$ , but for killer whales and sperm whales response were noted at the above-mentioned lower levels [Miller *et al.*, 2012]. Even lower response thresholds were found for harbour porpoises in a laboratory setting (Kastelein, 2012). Although this work provides useful information of relative impact of different frequencies and signals, the authors do not consider measurements in a controlled laboratory setting to be representative of the natural environment.

Here we propose  $SPL_0 = 130 \text{ dB re } 1 \mu\text{Pa}$  as a threshold for significant behavioural disturbance due to non-pulse sounds of short duration.

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<sup>4</sup> From p7, "Our results support a ... criterion of about 140 dB SPL for beaked whale exposure to mid-frequency sounds."

### 2.1.3 Choice of propagation loss model

Our purpose is to identify a source level threshold that is both realistic and conservative. This implies calculation of a reasonable lower limit on propagation loss (PL). Absorption is not relevant<sup>5</sup> at the frequencies of this indicator (low- and medium frequency i.e. below 10 kHz) and ranges (~ 1 km) considered here and therefore not used in the PL model.

#### SHALLOW WATER

At ranges of interest we expect mode stripping to give a conservative (lower limit) PL value (spherical and cylindrical spreading regions are restricted to distances up to a few water depths). For the sediment we choose medium sand because this results in good low frequency waveguide (by comparison, clay, silt and gravel are poor reflectors of sound [Ainslie 2010]).

Long range shallow water propagation at distances  $R$  of interest can be described by mode stripping, i.e. (see Ainslie 2010 chapter 9, pp 452-458)

$$PL(R) = 15 \log_{10} (R / r_{\text{ref}}) + 5 \log_{10} (\eta H / \pi r_{\text{ref}}) \text{ dB} \quad (1)$$

with:

$\eta$  = reflection loss gradient =  $\frac{1}{4}$  (representative of sand)

$H$  = water depth = 20 m

$r_{\text{ref}} = 1$  m

This equation, of the form  $PL = \text{constant} + 15 \log R$ , is more realistic than (say) cylindrical spreading, and by taking lowest reasonable values of  $\eta$  and  $H$  is a reasonable value for the shallow waters that are of interest; low frequency sound does not propagate well in water of depth less than 20 m. We therefore adopt the criterion

$$SL_E > SEL_0 + PL, \quad (2)$$

with PL given by eq (1). The equivalent inequality relating SL to SPL is

$$SL > SPL_0 + PL. \quad (3)$$

#### DEEP WATER

In deep water, we assume spherical spreading at short range, followed by cylindrical spreading (CS). For CS in a surface duct (surface sound speed  $c$ , sound speed gradient  $g$  and duct thickness  $D$ ) we use (see Ainslie, 2010, chapter 9):

$$PL = 10 \log_{10} (R / r_{\text{ref}}) + 5 \log_{10} [c D / (8g r_{\text{ref}}^2)] \text{ dB} \quad (4)$$

where  $R > (c D / 8g)^{1/2}$ .

Calculations with  $c = 1490$  m/s,  $D = 100$  m,  $g = 0.016$  /s show that deep water propagation loss is higher than the shallow water loss in the range 0-5 km. While a higher threshold could be considered for deep waters, for simplicity we advise use of a single threshold for data registration, irrespective of water depth. In subsequent analysis of register data it will be possible to distinguish between the very loud sources and the sources of less relevance.

<sup>5</sup> At 1 kHz, absorption is less than 0.1 dB/km, see <http://resource.npl.co.uk/acoustics/techguides/seaabsorp>

### 2.1.4 Choice of distance for potentially significant impact

We have to make a decision about the range or area within which displacement can be considered to be significant. In the reports of studies with harbour porpoises carried out in Germany and Denmark, displacement ranges around wind farm construction sites of magnitude 20 km are mentioned, implying an area of ca. 1250 km<sup>2</sup>. At this stage, there is concern that these kind of disturbance in combination with numbers of other similar events could lead to population level effects.

We do not know at what stage cumulative displacement effects will have a significant impact. However, a usable consideration on significance can be found in Southall *et al.* [2007], page 448:

*The NRC (2005) argued that, although the duration of behaviours likely to affect vital rates is believed to be particularly significant, current scientific knowledge is insufficient to support an analytical treatment of biological significance and ad hoc criteria are needed in the interim. Here, substantive behavioral reactions to noise exposure (such as disruption of critical life functions, displacement, or avoidance of important habitat) are considered more likely to be significant if they last more than one deil period, or recur on subsequent days. Consequently, a reaction lasting less than 24 h and not recurring on subsequent days is not regarded as particularly severe unless it could directly affect survival or reproduction.*

A 24 hour time-period is too long if we want to make sure that we stay in the ‘no-effect’ range. For instance, important species like harbour porpoises have a high digestive rate and have to forage many times per day (see e.g. [Kastelein *et al.*, 1997]). If evasive movement influences its ability to forage for several hours, a porpoise already starts depleting energy reserves. The Commission Decision of 2010 requires MS to assess the activities per day, but that does not mean that duration of the response must be on the order of one day, exposure of shorter duration can have negative effects. TSG Noise therefore advises to start registering sources that have the potential for displacement. Further, we want to make a translation from ‘time’ to ‘distance’. And for the chosen value for distance to be acceptable, we advise a precautionary value but avoid choosing a value that is unnecessarily low and thereby unworkable.

This was discussed within TSG Noise in the October 2012 meeting in Ireland. For instance, considering the possible effects at zero range would lead to an unworkable situation - we do not use that approach when assessing other forms of pollution. For this particular effect, the minimum for the range of interest would be at a scale less likely to have a significant habitat loss. TSG Noise initially proposes to use the (1000 m) range to take up sources in the register, but this could be reviewed at a later stage (e.g. the foreseen 6-year review of the Commission Decision on the indicators in 2016).

The PL over such a range can easily be calculated using the methodology described above for shallow water. For several possible ranges the PL is shown in Table 1.

Range	PL [dB re 1 m]	SL <sub>E</sub> needed <sup>6</sup> [dB re 1 μPa <sup>2</sup> m <sup>2</sup> s]
100 m	31.0	171.0
300 m	38.2	178.2
1000 m	46.0	186.0
3000 m	53.2	193.2

**Table 1: Propagation loss (PL), evaluated using Eq. (1), for different ranges and energy source level (SL<sub>E</sub>) that would lead to the single pulse SEL value of 140 dB re 1 μPa<sup>2</sup> s for multiple-pulse sources (like piling and airguns) at that range.**

<sup>6</sup> The reference value is sometimes written “1 μPa<sup>2</sup> s @ 1 m” instead of “1 μPa<sup>2</sup> m<sup>2</sup> s”. The latter is preferred because «1 μPa<sup>2</sup> s @ 1 m» is not an SI unit. The intended meaning is the same.



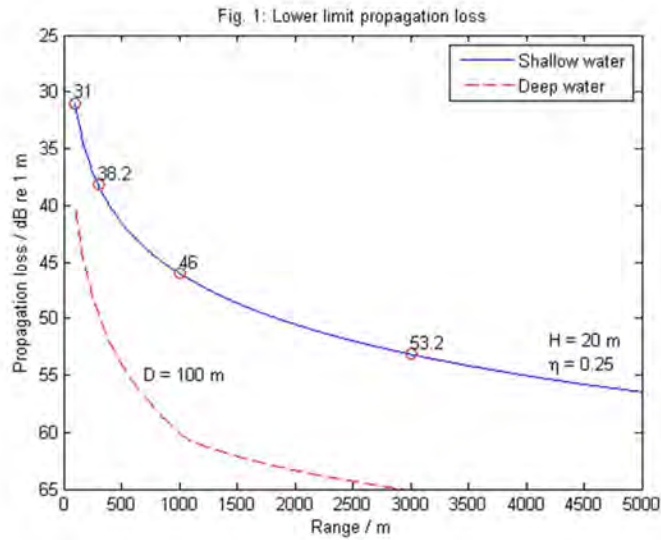


Figure 1: Propagation loss [dB re 1 m] vs range [m].

PL is calculated using eq. (1), which assumes negligible absorption and is consequently independent of frequency. Equation (1) provides a lower limit on PL and is therefore precautionary. The solid blue line in the above figure shows the expected lower limit for propagation loss in shallow water. The estimated lower limit for PL in deep water (dashed red line) is higher than the shallow water lower limit, so the shallow water curve may be used as an overall lower limit for effects up to 5 km.

Since we are interested in effects at distances of order 1000 m range we choose to use the  $SL_E$  value obtained for this range as the recommended minimum to take up multiple pulse sources in the register: 186 dB re  $1 \mu Pa^2 m^2 s$ .

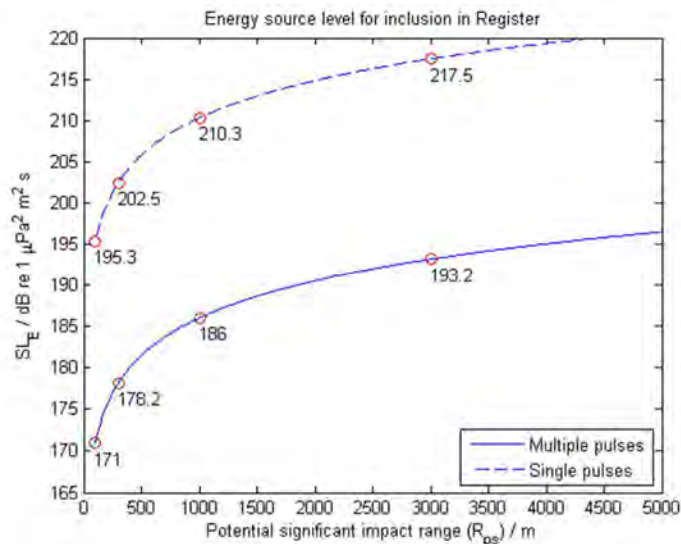


Figure 2: Energy source level threshold [dB re  $1 \mu Pa^2 m^2 s$ ] vs significant impact range [m].

Since we are interested in effects at distances of order 1000 m we use the  $SL_E$  value obtained for this range as the recommended minimum to take up single pulse sources in the register: 210 dB re  $1 \mu Pa^2 m^2 s$ .

Range	PL [dB re 1 m]	SL <sub>E</sub> needed [dB re 1 μPa <sup>2</sup> m <sup>2</sup> s]
100 m	31.0	195.3
300 m	38.2	202.5
1000 m	46.0	210.3
3000 m	53.2	217.5

Table 2: PL for different ranges and SL<sub>E</sub> that would lead to the single-pulse SEL value of 164.3 dB re 1 μPa<sup>2</sup> s for single pulse sources (explosives) at that range. The conversion from SL<sub>E</sub> to TNT charge mass is made in Table 4.

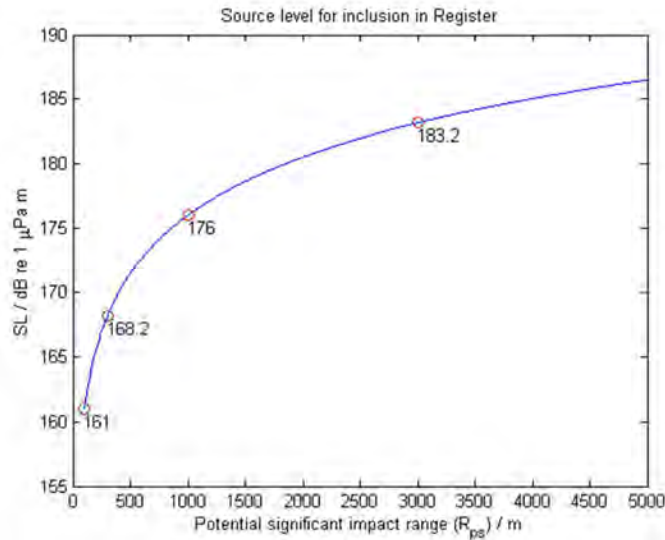


Figure 3: Source level threshold [dB re 1 μPa m] vs significant impact range for sonar [m].

Range	PL [dB re 1 m]	SL needed <sup>7</sup> [dB re 1 μPa m]
100 m	31.0	161.0
300 m	38.2	168.2
1000 m	46.0	176.0
3000 m	53.2	183.2

Table 3: PL for different ranges and SL that would lead to the single-pulse SPL-value of 130 dB re 1 μPa for non-impulsive sources (sonars) at that range.

Since we are interested in effects at distances of order 1000 m we use the SL value obtained for this range as the recommended minimum to take up non-pulse sources in the register: 176 dB re 1 μPa m.

### 2.1.5 Choice of proxy and implications

Sources other than sonars and acoustic deterrents are rarely characterised by their source level (whether SL or SL<sub>E</sub>). For each source it is convenient – and for some sources, essential – to find a proxy that is more widely used and still makes sense.

The acoustic strength of sonars and acoustic deterrents is routinely reported in terms of source level, so no proxy is needed for these. The strength of explosions is widely reported in terms of TNT equivalent charge mass ( $m_{TNTeq}$ ). The strength of airgun arrays is widely reported in terms of their far-field source signature (product of distance from the airgun array and far-field sound pressure at that distance, usually in the vertical direction, immediately beneath the array), the maximum magnitude of which is known as

<sup>7</sup> The reference value is sometimes written «1 μPa @ 1 m» instead of «1 μPa m». The latter is preferred because «1 μPa @ 1 m» is not an SI unit, but the intended meaning is the same.

“source strength”  $A$  [Dragoset, 2000]. This quantity is related to the zero to peak source level [Ainslie (2010), p 431] of the dipole formed by airgun array plus surface image according to

$$SL_{zp} = 10 \log_{10} (A^2 / (\mu\text{Pa}^2 \text{ m}^2)) \text{ dB} \quad (5)$$

The quantity  $SL_{zp}$  is referred to by [Ainslie (Ed.), 2011] as “peak pressure dipole source level”

The strength of impact of pile drivers is sometimes reported in terms of source level, but doing so leads to problems of interpretation [Ainslie *et al.*, 2012, "Aquatic Noise 2012"]. Instead we propose hammer energy ( $E_{\text{hammer}}$ ) as a suitable proxy.

## 2.1.6 Conversion to proxies

### AIRGUN ARRAY

The acoustic strength of an airgun array can be characterised by its zero to peak source level  $SL_{zp}$

If one can characterise the pulse of an airgun array by a single cycle of period  $\tau$ ; then:

$$SL_E = 10 \log_{10} [(1/2) \tau / \text{s}] \text{ dB} + SL_{zp} \quad (6)$$

Combined with  $SL_E = 186.0 \text{ dB re } 1 \mu\text{Pa}^2 \text{ m}^2 \text{ s}$  gives  $SL_{zp} = 209.0 \text{ dB re } 1 \mu\text{Pa m}$ , ( $\tau = 10 \text{ ms}$  is assumed, representing the period of the single cycle).

Notes:

- Source level of an airgun array is measured in the direction of its main beam. For the environmental relevance, the source level in the horizontal plane or at a certain angle of relevance from the acoustic axis is preferred and therefore information on directivity should preferably be added. If this is not possible the usually provided value in the vertical direction will be used (acknowledging that this overestimates the amount of energy trapped in water column)
- Because the strength of an airgun array is specified in terms of peak sound pressure and because peak pressure is sensitive to bandwidth, it becomes necessary to specify a frequency band. Based on the Descriptor text, the range 10 Hz to 10 kHz seems appropriate. However, there might be a case for lowering the upper limit of this frequency range to 1 kHz. This is because in reality what matters

is  $SL_E$  rather than  $SL_{zp}$ , and the integral  $\int p(t)^2 dt$  is dominated (because of the assumed 10 ms period) by sounds ca. 100 Hz.

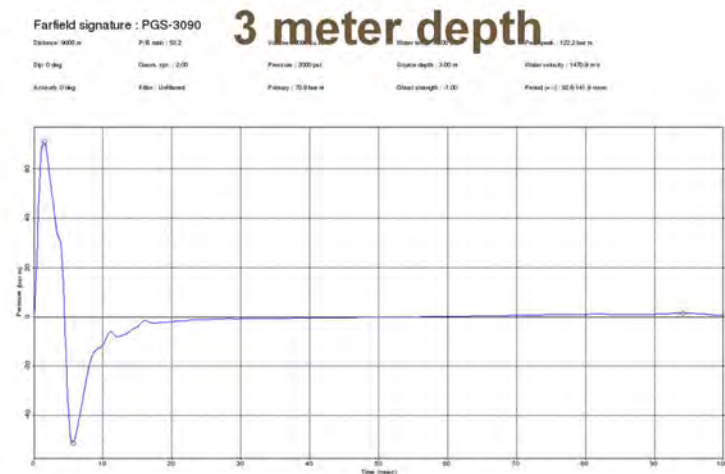


Figure 4: Farfield signature: PGS-3090; 3 m depth: Airgun signature in bar metres (bar m) (supplied by W Pramik, Geokinetics).



Figure 5: Farfield signature: PGS-3090; 9 m depth: Airgun signature in bar metres (bar m) (supplied by W Pramik, Geokinetics).

The duration of the first full cycle is between 10 ms and 20 ms. In both cases the source strength  $A$  is about 67 bar m, corresponding to a zero to peak source level of 257 dB re  $1 \mu\text{Pa m}$ .

## EXPLOSIONS

Explosives are usually characterised by means of their “equivalent TNT charge mass”, defined as the mass of TNT that would release the same amount of explosive energy. This mass, denoted “ $m_{\text{TNTeq}}$ ”, is related to  $\text{SL}_E$  via [Ainslie, 2010] (excluding bubble pulses):

$$\text{SL}_E = 231 \text{ dB re } 1 \mu\text{Pa}^2 \text{ m}^2 \text{ s kg}^{-1} + 10 \log_{10}(m_{\text{TNTeq}}/\text{kg}) \text{ dB} \quad (7)$$

$$m_{\text{TNTeq}} = 10^{(\text{SL}_E - 231)/10} \text{ kg} \quad (8)$$

substituting  $\text{SL}_E = 210.3 \text{ dB re } 1 \mu\text{Pa}^2 \text{ m}^2 \text{ s}$  for a single explosion gives  $m_{\text{TNTeq}} = 8 \text{ g}$ .

## IMPACT PILE DRIVER

The international workshop of February 2011 concluded that a definition of source level for a pile driver is not yet available [Ainslie (ed) 2011]. Instead impact pile drivers are usually characterised by means of their hammer energy (sum of potential and kinetic energy at the moment of impact with the pile), providing a suitable proxy. The energy radiated as sound can be expressed as a proportion of the hammer energy

$$(E_{\text{ac}})_{\text{pile}} = \mu E_{\text{hammer}}, \quad (9)$$

where  $\mu$  is the constant of proportionality.

It is straightforward to convert the energy source level threshold to an energy threshold defined as the acoustic energy that would be radiated from an omnidirectional source of energy source level equal to the  $\text{SL}_E$  threshold.

$$(E_{\text{ac}})_{\text{threshold}} = 10^{(\text{SL}_E - 170.7)/10} \text{ J} \quad (10)$$

Using eq. (5) and (6), one can then compare the energies instead of the source level. Requiring their right hand sides to be equal results in the following expression for  $E_{\text{hammer}}$

$$E_{\text{hammer}} = \frac{1}{\mu} 10^{(SL_E - 170.7)/10} \text{ J} \quad (11)$$

With  $SL_E = 186.0 \text{ dB re } 1 \mu\text{Pa}^2 \text{ m}^2 \text{ s}$ ; putting  $\mu = 0.03$  (a realistic value; factor 2 higher than available measurements = 1-2%); [de Jong & Ainslie 2008 (1%); Zampolli *et al.*, 2013 (2%)]. A threshold of 1.13 kJ follows. This is much lower than typical values used for offshore construction (hundreds of kilojoules). It is therefore proposed to include all impact pile driving in the Register.

The above conclusions for impact pile drivers do not depend on the precise choice of  $R_{ps}$ . They would follow also from a choice of 100 m or 3000 m for this range.

### 2.1.7 Conclusions

The source level threshold for a non-pulse (sonar etc), derived from Table 3, is 176 dB re 1  $\mu\text{Pa}$  source level threshold for a non-pulse (sonar etc), derived from Table 3, is 176 dB re 1  $\mu\text{Pa}$  m.

	Impact pile driving	Seismic survey (airgun array)	Explosions
<b>SL<sub>E</sub> threshold for Register</b>	186 dB re 1 $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$	186 dB re 1 $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$	210 dB re 1 $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$
<b>Proxy</b>	Hammer energy $E_{\text{hammer}}$	Zero to peak source strength $SL_{zp}$	TNT charge mass $m_{\text{TNTeq}}$
<b>Derived proxy threshold for Register</b>	1.1 kJ	207 dB re 1 $\mu\text{Pa}$ m	8 g

Table 4: Derived proxies for multiple pulses and explosions.

Converting to the various proxies, as explained in Sec. 2.1.6, gives the following criteria for inclusion in the Register of low and mid-frequency sources:

Airgun (see sec 2.1.6):	$SL_{zp} > 209 \text{ dB re } 1 \mu\text{Pa m}$
Low-mid frequency sonar:	$SL > 176 \text{ dB re } 1 \mu\text{Pa m}$
Low-mid frequency acoustic deterrent:	$SL > 176 \text{ dB re } 1 \mu\text{Pa m}$
Explosions (see sec 2.1.6):	$m_{\text{TNTeq}} > 8 \text{ g}$

The minimum hammer energy needed is very low (compared to the values of this parameter encountered in practice) and a minimum threshold would not be relevant. All licensed pile driving activity associated with offshore construction would be included in the Register.

### 2.1.8 Further improvements: further details of data collection

The thresholds that were derived will ensure that all sources that have a potential for significant effect will be included in the register. However, these relatively low thresholds imply that sources will be registered that actually will have a relatively low impact, e.g. sonars whose source level is less than 200 dB re 1  $\mu\text{Pa}$  m, while there are much stronger sources that may have a much greater impact (e.g. sonar sources that have a source level around 230 dB re 1  $\mu\text{Pa}$  m). TSG Noise noted that there is a need for more details in the register than only the pulse-day level suggested by TG11. For example not only the day, but also the number of noise-producing events, and the source level of each might be recorded if they are available to be used at a later stage. Further information would be helpful in both roles of the register to record what has happened and to act as a potential planning tool for future activities.

It is proposed that the following additional information be gathered in the register, which will further enable MS to assess the magnitude of impact of sounds sources:

#### SOURCE PROPERTIES

1. Source level or proxy;
2. Source spectra;
3. Duty cycle;
4. Directivity;
5. Duration of transmissions;
6. Platform speed.

Of this list, an estimate of the first five would be needed to calculate the free-field energy, a measure of environmental cost proposed by [Ainslie & Dekeling, 2011]. Platform speed also determines size of impacted area so collecting this data may be useful.

In order to assess which sources, of those included in the Register contribute to the Indicator 11.1.1, it is necessary to determine whether they have significant impact. To achieve this, TSG Noise considers it necessary that at least the source level (or proxy) and the number of times a source is used per day are registered. In order to give operators, e.g., navies using sonar, oil and gas companies using airguns, the option of not disclosing sensitive detailed information of source properties, e.g. sonar source level is often considered classified. It is proposed that not the specific level is registered but that operators will have the option to report source level as follows:

#### **Sonars or acoustic deterrents (source level, rounded to nearest decibel):**

- Very low: 176-200 dB re 1  $\mu\text{Pa m}$
- Low: 201-210 dB re 1  $\mu\text{Pa m}$
- Medium: 211-220 dB re 1  $\mu\text{Pa m}$
- High: above 220 dB re 1  $\mu\text{Pa m}$

#### **Generic explicitly impulsive source (energy source level, rounded to nearest decibel):**

- Very low: 186-210 dB re 1  $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$
- Low: 211-220 dB re 1  $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$
- Medium: 221-230 dB re 1  $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$
- High: above 230 dB re 1  $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$

#### **Airgun arrays (zero to peak source level, rounded to nearest decibel):**

- Very low: 209-233 dB re 1  $\mu\text{Pa m}$
- Low: 234-243 dB re 1  $\mu\text{Pa m}$
- Medium: 244-253 dB re 1  $\mu\text{Pa m}$
- High: above 253 dB re 1  $\mu\text{Pa m}$

#### **Explosions (equivalent TNT charge mass, rounded to nearest 10 g if less than 10 kg and to nearest 1 kg otherwise)**

- Very low: 8 g to 210 g
- Low: 220 g to 2.1 kg
- medium: 2.11-21 kg
- high: 22-210 kg
- Very high: above 210 kg

#### **Impact pile driver (hammer energy, rounded to nearest 10 kJ)**

- Very low: less than 280 kJ
- Low: 290 kJ-2.80 MJ
- Medium: 2.81-28 MJ
- High: above 28 MJ



## 2.2 Proposal for establishing national and a common Regional Sea noise registry

(Authors: M.L Tasker, R.P.A. Dekeling, P Redman)

The objective of the noise register is to develop a large scale picture of the occurrence of loud impulsive sounds in national and regional seas, information that is not available in any coherent way at the moment. It is plainly of benefit that national work be compatible across marine boundaries. This is the main underlying reason for the establishment of TSG-Noise. All European MS were asked to supply information on loud impulsive underwater sounds to TSG-noise in order that the group could learn from existing efforts and to determine what information was readily available for use. Information was forthcoming from the UK, the Republic of Ireland and The Netherlands. The following proposal is therefore based on that somewhat limited dataset.

The information provided by the three Member States was basically all that was available arising from the processes used to regulate activities under European (primarily the EIA Directive) or national legislation. TSG-noise notes this pragmatism and considers that such information will cover a very high percentage of all relevant impulsive sound occurring in Europe's seas. Adding other noise sources to registers may not have enough added value in relation to the added cost.

The following notes are based on analysis of data on seismic sources in UK waters. In this case, three main types of information are available:

- a) the forms used to apply for consent or to notify authorities of the intention to carry out a seismic survey
- b) the “close-out” reports made by many operators after the seismic survey
- c) the reports made by marine mammal observers and/or passive acoustic monitoring personnel placed on board all seismic vessels in UK waters under the consent conditions for those surveys.

Type a) differs from types b) and c) because these forms are completed before the survey and no plans are ever followed exactly – weather, ship availability and equipment issues are all factors that affect actual practice. Both type a) “prior to activity” and types b) / c) “after activity” are required; the former is needed should management of activity be required, while the latter gives a truer picture of what happened. This is an important principle in the establishment of a noise register.

In the UK at present the close-out reports are not detailed enough (e.g. pulse-block-days are difficult to derive from them), but this is being addressed. Full reports from marine mammal observers and/or passive acoustic monitoring personnel are generally the most detailed, but certainly not perfect, source; manually plotting the effort data from these reports is currently the only way to determine pulse-days and this is very labour intensive. These reports may also be limited to a pre-firing check or daylight hours/good weather, which means a lot of location data on when the guns were actually firing may be missing.

For seismic activities it may be simpler (and sufficient for some purposes) to provide a monthly overview of noise per block, but for other activities (e.g. piling for wind farms) it may be easier to collect data on actual lat/long positions. Naval operators may prefer to report in operating areas/exercise areas that are of different size and structure than the seismic blocks. Exercising naval units normally use dedicated areas for specific training as in the map shown here, e.g. ‘Navy Area Charlie’ is the area where helicopter sonar training can be executed; ‘Charlie’, or ‘Charlie South’ could be used for reporting.

### **Text box 1: Variable scale operating areas**

- In the **UK**, offshore leases are normally granted in 10X12 minute blocks (or subdivisions thereof), this may be different per MS; in the **Netherlands** no fixed block size is used
- Various military exercise areas and testing range exist but these are not typically of a standard size (although local subdivision may be).



Figure 6: Map of military operating areas in the Netherlands part of the North Sea.

### 2.2.1 Collation of data

Member States should attempt to ensure that as much relevant data as possible are collated, whilst trying to prevent any duplication. Duplication occurs mostly in “after activity” data as there may be multiple sources. Duplication of data would also need to be considered at boundary areas (e.g. where surveys regularly cross between UK and Norwegian waters) if data from different member states is collated at a later stage.

Standardised filenames, possibly using the consent (legal) reference within the filename, help considerably in sorting information. Where this is not possible (and also to reduce the length of filenames) there should be a set protocol for renaming and saving files so that they are easy to locate and check with the consent data. Data files should be checked for quality assurance as soon as possible after they are received. The minimum check would be:

- 1) that required files are included in an appropriate format (e.g. excel spread sheet).
- 2) that consent number and dates agree within files (check each sheet within the excel file) and between the written report and excel spread sheet.
- 3) That the details of the survey (e.g. location, dates, size of airguns etc) match those with the consent number from the licensing authorities (i.e. the correct consent number has been attached to the report/spread sheets).

In order to ascertain if all data/surveys are being added to the Register, it is important to keep track of all three types of data and cross-check these in order to chase up on missing data; it is also important to receive notification of when surveys get amended, cancelled or extended.

Many errors occur within the submitted reports – obvious errors can sometimes be corrected but it is not always possible to determine what the correct value should be. This highlights the importance of ensuring that files are submitted as soon as possible and checking files soon after they are received to allow errors to be rectified quickly.

### 2.2.2 Information to be included in the register

For the future register, the following data should be collected:

Position data (geographic position (lat/long), licensing block/area)

Date of operation

Source properties:

Essential (minimum)

- Source level or proxy;

Additional data will be beneficial for improved assessment - where available the following may also be recorded:

- Source spectra;
- Duty cycle;
- Duration of transmissions (and actual time/time period);
- Directivity<sup>8</sup>;
- Source depth;
- Platform speed

Of the source properties listed, the source level (or proxy) is the most important one. It is possible that many operators (e.g. navies using sonar, oil and gas companies using airguns) may have concerns about releasing sensitive or commercially valuable information. Where detailed information of source properties is requested it is proposed that certain operators be given the option to report source level in bins (of e.g. 6 dB, or 10 dB) rather than giving a precise figure.

### 2.2.3 Issues for a common register between Member States

TSG Noise recommends the setting up of a joint register of the occurrence of impulsive sounds at least on a Regional Sea level.

The final format for the common register needs to be established to ensure future compatibility. This cannot be conclusively decided until the register location and management are decided, but some factors could be implemented now, such as:

- ✓ Use of a common language (English)
- ✓ Use of a common format for date in accordance with the appropriate standard (ISO 8601) (YYYY-MM-DD or YYYYMMDD)
- ✓ Use of a common format for position (latitude and longitude, decimal degrees)
- ✓ Use of a common map projection (unprojected data – WGS84)
- ✓ Use of a common template (i.e. setting out the order in which information is recorded)

#### The use of grids, grid definition and size

As mentioned above, for some of the data (e.g. seismic survey data) the use of a grid (based on standard licensing blocks) may be practicable to collect (part of) the data on impulsive noise. Member States may choose to use such a grid to organise data (for instance, use the above-mentioned blocks to store data instead of the actual positions of a piling activity). Member states may also choose to use such a grid for other purposes e.g. presenting data, assessment purposes and for future management action.

In such cases, the actual choice of grid definition, and the size of the grid cells, is a choice that should be made by Member States and this can be based on practical considerations, e.g. in the UK, data are registered in standard hydrocarbon licensing blocks that are 10 minutes latitude by 12 minutes longitude. If the grid is to be used for assessment purposes, a possible option is to base the grid on estimated impact (e.g. the reported effect range for harbour porpoises is 20 km [Tougaard *et al.*, 2012]) (A circle with a radius of 20 km has an area of ca. 1250 km<sup>2</sup>. TG 11 suggested blocks of 15 minutes by 15 minutes. At a

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<sup>8</sup> Much of the energy from airguns is directed downwards, and therefore directivity data are needed to assess their significance. Directivity plots are routinely produced by seismic survey companies in advance of carrying out their surveys. If this information is made available (if possible in digital form), MS can include this information when assessing possible effect ranges and thereby improve the assessment. If for other sources the producer of the sound wants the directionality to be taken into account, that producer should provide the necessary information.

latitude of 45 degrees North this would give an area of about 550 km<sup>2</sup>. For easier interpretation of results in a common register, TSG Noise would recommend one grid size to be used by Member States.

If the grid chosen by Member States is to be used for assessment purposes, it should be noted that it may not be of the same spatial scale as the area actually affected by the noise source. The number of days (or percentage) that activities occur should not be interpreted as a direct measure of habitat loss (holes in distribution). This may not be a problem - a correction factor could be applied when comparing results that are generated using different grid sizes, or if the grid sizes are not appropriate for definitions of targets. This correction factor could, in principle, be based on the ratio of expected impact size to registry grid size. (see Van der Graaf et al., 2012).

There may also be issues for grid cells in coastal areas or at boundaries between Member States. For these blocks some additional considerations may apply.

#### ***Coastal blocks and Boundary blocks – special considerations for inclusion in a noise register***

There are two areas where additional factors for monitoring pulse-block-days may need to be taken into consideration:

##### 1) Coastal areas

- Blocks may be smaller than standard size
- Blocks may contain transitional waters (not directly covered by MSFD)
- Blocks may contain unconnected bodies of water (blocks which are bisected by a landmass)

##### 2) Boundary areas between Member States

- Blocks may be smaller than standard size
- Seismic surveys may cross the boundary line

These blocks can be flagged in a registry to allow additional information to be collected. Member States need to consider whether part-blocks need to be treated differently to complete blocks (this may depend on the amount of water within the block) and ensure that duplication is prevented at boundary areas. Noise in transitional waters has the potential to impact on the MSFD area and should be included in the registry, but a realistic cut-off point needs to be applied e.g. when deciding how far upriver noise should be monitored.

### UK example – coastal blocks

A simple set of rules has been suggested for collating additional information for coastal blocks in the UK register. Within the database, any block containing part of the UK coastline will be coded for three attributes:

- a) Whether or not the block contains <5% water: yes/no. This 5% rule includes transitional waters, which will be included in the UK register.
- b) The type of water in the block:
  - i. coastal
  - ii. transitional, or
  - iii. includes both coastal and transitional waters
- c) Whether or not the block is split: yes/no. A block will be considered split if
  - i. it contains both coastal and transitional waters,
  - ii. land bisects the block such that water bodies within it are completely separated, or
  - iii. it contains islands, enclosed bays or other features which make it difficult to judge how noise will propagate through the water in the block.

It is proposed that the UK register is developed so that noise occurring in coastal blocks containing <5% water is allocated to an adjacent block for mapping of data (this 5% rule will also provide a cut-off point for how far upriver data is to be collated) and lat/long are requested for activities in split blocks or for activities in transitional waters. This additional information can be used to exclude data from analyses if required and will provide more accurate information on noise within specific blocks if the register is to be used to regulate activities in the future.

### Boundary Blocks:

It is necessary to provide guidance to ensure that information collected by Member States from boundary areas is not duplicated in a common register. It is therefore advisable that data uploaded to the common register contains information at the level of individual days (i.e. it is not uploaded to the common register as 'days per month' per block). In areas where the block sizes are the same, partial blocks will line up with one another along the boundary line and this will allow duplicate data to be readily identified. However, where block sizes are different, partial blocks may be staggered, making it more difficult to determine what constitutes duplicated data. Other issues, e.g. different time zones, variations in the details recorded, etc. can only be addressed when we know the areas to be covered by a common register.

## 2.3 Noise maps for shipping and explosions in the Dutch North Sea

(Authors: M.A. Ainslie & O. Sertlek)

### SUMMARY

The purpose of this section is to illustrate the potential for noise mapping. This purpose is met by providing examples of noise maps for two very different kinds of anthropogenic sound source: shipping and explosions. Maps for both types of source are provided and conclusions are listed.

### 2.3.1 Introduction

The Marine Strategy Framework Directive defines Good Environmental Status (partly) in terms of Indicator 11.2.1. This Indicator (henceforth “Indicator 2”) requires Member States to monitor annually averaged noise in third octave bands centred at 63 Hz and 125 Hz. The purpose of this section is to present annually averaged noise maps in one of these frequency bands for selected anthropogenic noise sources for the Dutch Exclusive Economic Zone in the North Sea (hereafter referred to as the “Dutch North Sea”). See Figure 7 (below).

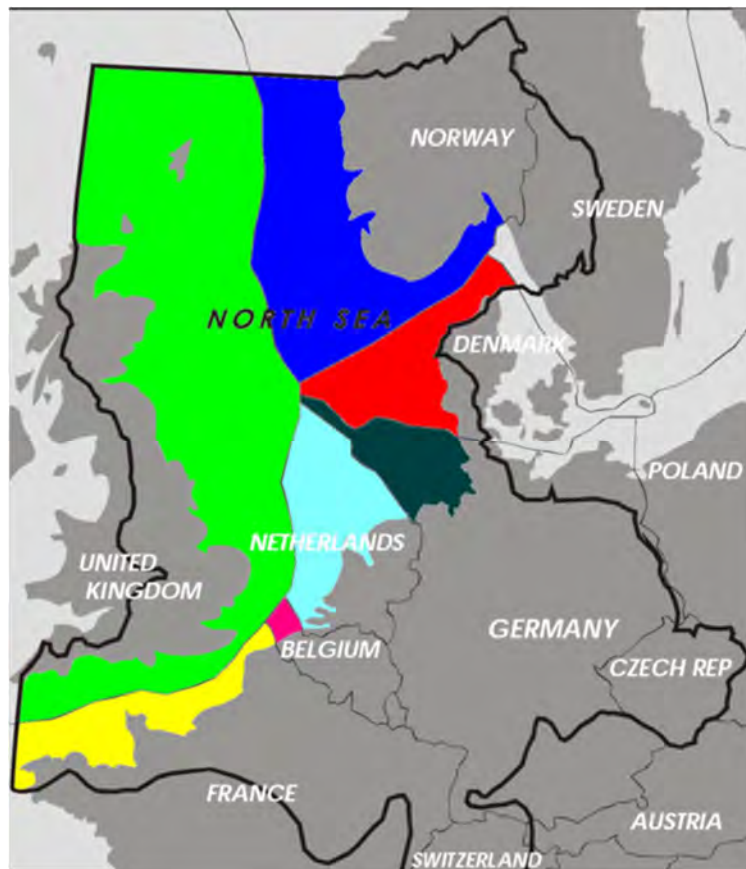


Figure 7: North Sea Exclusive Economic Zones. The region covered by this memo is the cyan region marked “NETHERLANDS”.



## 2.3.2 Sources considered

### Anthropogenic sources

The purpose of Indicator 2 is to monitor underwater sound in a frequency band representative of shipping noise (decidecades<sup>9</sup> centred at 63 Hz, 125 Hz). This memo focuses on 125 Hz. In the North Sea, results for 63 Hz are expected to be similar.

Ainslie *et al.* [2009] identifies four main sources of low frequency underwater sound, all of which can be expected to contribute to Indicator 2 in the North Sea: air guns (seismic surveys), shipping, explosions (detonation of unexploded WW2 ordnance) and impact pile driving (mainly associated with wind farm construction). According to Ainslie *et al.* [2009]:

- Seismic surveys carried out in the Dutch North Sea in 2007 involved 3D surveys covering a total area of 1400 km<sup>2</sup> and 2D surveys covering a distance of 150 km;<sup>10</sup> the estimated zero to peak source level of a typical air gun array used in these surveys is 255 dB re 1 µPa m.
- “the average number of ships per year in the Netherlands Exclusive Economic Zone (EEZ) in the years 1999 to 2001 was 336.”<sup>11</sup>
- The number of controlled detonations that took place in the Dutch North Sea in 2008 was 136, with an average TNT charge weight per detonation of 78 kg.
- Assuming a wind turbine capacity of 2 MW per turbine, wind farm construction in the Dutch North Sea would result in the installation of 2904 new turbines by 2020 (264 per year on average from 2009 to 2020).

Based on these data, the four activities mentioned were estimated by [Ainslie *et al.*, 2009] to contribute 8000 kJ, 3000 kJ, 700 kJ and 500 kJ, respectively, to the annually averaged free-field sound energy [Ainslie & Dekeling 2011] in the Dutch North Sea. These are the only activities whose total predicted free-field energy contributions in the Dutch North Sea exceed 10 kJ.<sup>12</sup> They are given special attention for the present work because the authors consider them the main anthropogenic contributors to low frequency underwater sound.

This memo concentrates on shipping and explosions (see Table 5). Source distributions are shown for shipping in Figure 8 (average distribution for the year 2007) and for explosions in Figure 9 (averaged over the period 2010-2011).

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<sup>9</sup> The term “third octave band” is interpreted as one tenth of a decade (a decidecade).

<sup>10</sup> source: Jaarverslag Staatstoezicht op de Mijnen 2007

<sup>11</sup> this is an error; it should read “number of ships ... was 336 in the Netherlands [EEZ]” and not “number of ships per year ... was 336 in the Netherlands [EEZ]”

<sup>12</sup> In fifth place, at 2 kJ, was expected future sonar use, two orders of magnitude smaller than the fourth place (wind farm construction).

Type of source	Source distribution from	Start date	End date	Duration	Source level	Source depth
shipping	AIS	Jan 2007	Dec 2007	1 year	[Wales & Heitmeyer 2002]	4 m
explosions	RNLN	Jan 2010	Dec 2011	2 years	[Weston 1960]	equal to water depth

Table 5: Overview of data used for calculation of noise maps for shipping and explosions.

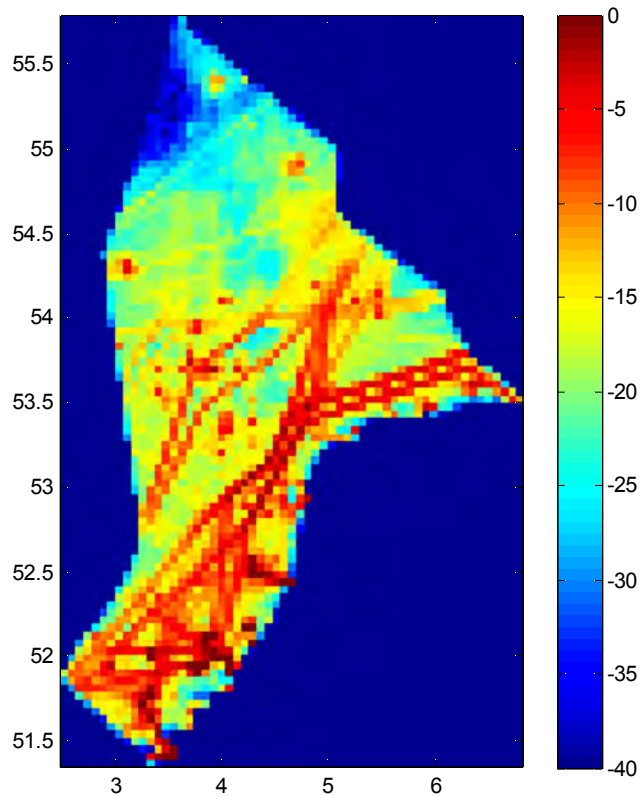


Figure 8: Distribution of shipping density  $10\log_{10}(25 N/\text{km}^2)$  where  $N$  is the average areic shipping density in 2007 (data obtained from IMARES).

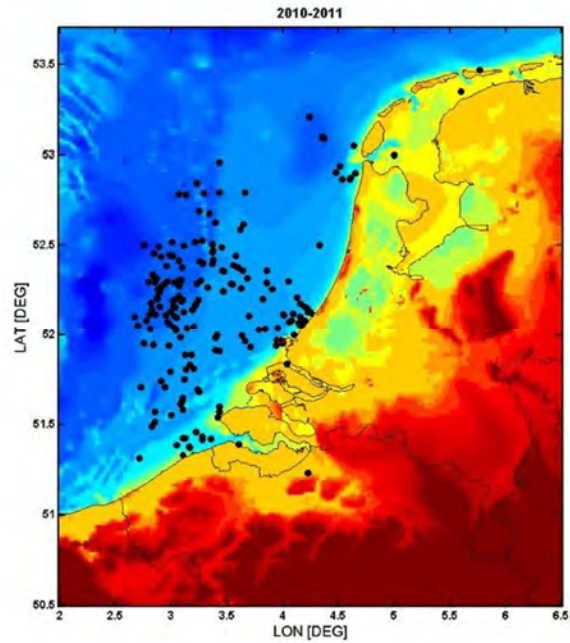


Figure 9: Distribution of explosions in 2010 and 2011 (data from RNLN).

### Natural sources

Although noise maps for natural sources are not included here, it is useful to consider the range of likely levels of natural noise, as this helps in the interpretation of the maps of anthropogenic sound. For wind speed see Figure 10.

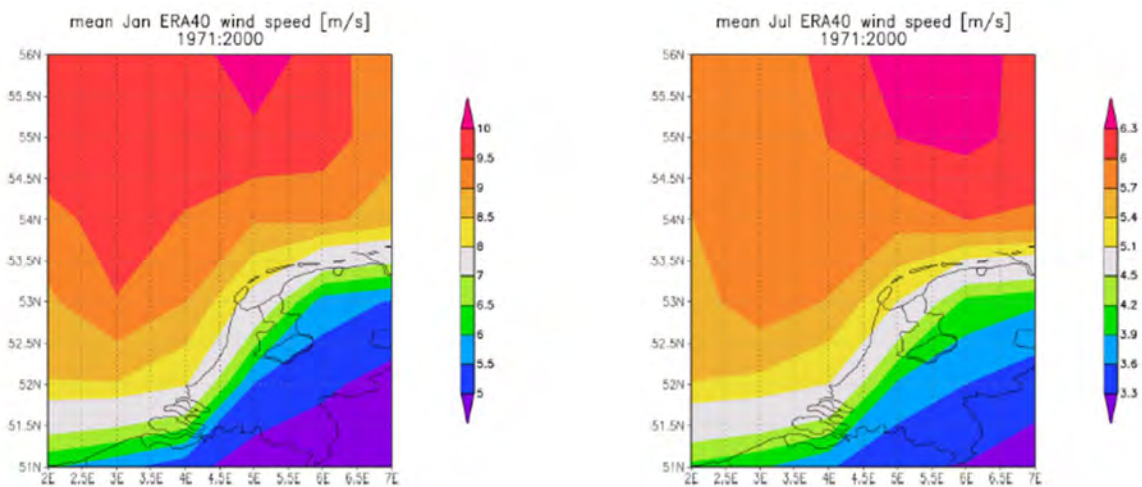


Figure 10: Map of mean wind speed in January (left) and July (right). Figure from Ainslie et al. [2009].

For the range of wind speed 5 m/s to 10 m/s, the areic spectral density dipole source level at 125 Hz is in the range 55 dB to 62 dB re  $1 \mu\text{Pa}^2/\text{Hz}$  (Figure 10). The noise level in deep water can be estimated by adding 5 dB to this value [Ainslie 2010], giving a wind noise spectral density level of 60 dB to 67 dB re 1

$\mu\text{Pa}^2/\text{Hz}$ , corresponding to sound pressure level (SPL) between 75 dB and 82 dB re 1  $\mu\text{Pa}$  in the decade centred at this frequency. In shallow water, additional contributions can be expected from seabed reflections, with resulting noise levels in coastal water “5 to 10 dB higher than in deep water far from shore at frequencies greater than about 500 Hz” [Urick, p. 213]. For example, a difference of 7 dB would result in a range of 82 dB to 89 dB re 1  $\mu\text{Pa}$  in shallow water. This seems consistent with the predicted maxima of 91 dB and 96 dB re 1  $\mu\text{Pa}$  (for July and January, respectively) for the frequency band 10 Hz to 1 kHz, from [Ainslie *et al*, 2009].

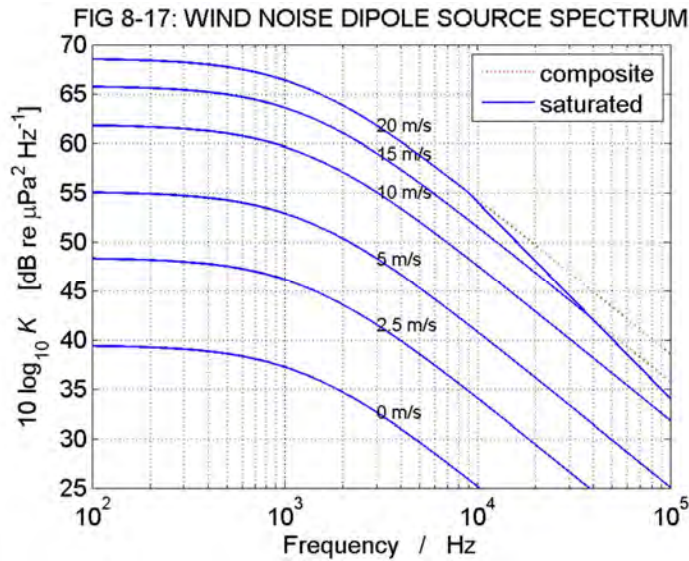


Figure 11: Arctic spectral density dipole source level due to wind (from [Ainslie (2010)] © Springer).

### 2.3.3 Noise maps

Two noise maps are presented in this section, one for shipping and one for explosions. Both are for annually averaged squared pressure in the decade centred at 125 Hz, expressed as a level in decibels and for a receiver placed at depth 1 m from the sea surface.

Input parameters used for both maps are:

Wind speed = 0

Sediment = medium sand [Ainslie 2010]

Bathymetry = ETOPO1 (interpolated with 5 km resolution)

Sound speed profile = isovelocity

#### Shipping

The left graph of Figure 12 shows predicted sound pressure level in the decade band centred at 125 Hz associated with the shipping distribution of Figure 8. According to this distribution, the average number of ships in the Dutch North Sea in 2007 was 259, of which 248 are taken into account in the present calculations. The shipping distribution and therefore the resulting noise map are averaged over one year (January to December 2007). Shipping noise so calculated is between 50 dB and 100 dB re 1  $\mu\text{Pa}$  on most of the Dutch North Sea. The bright spots near the coastline centred at approximately 50 km E, 450 km N are probably artefacts and should be disregarded.

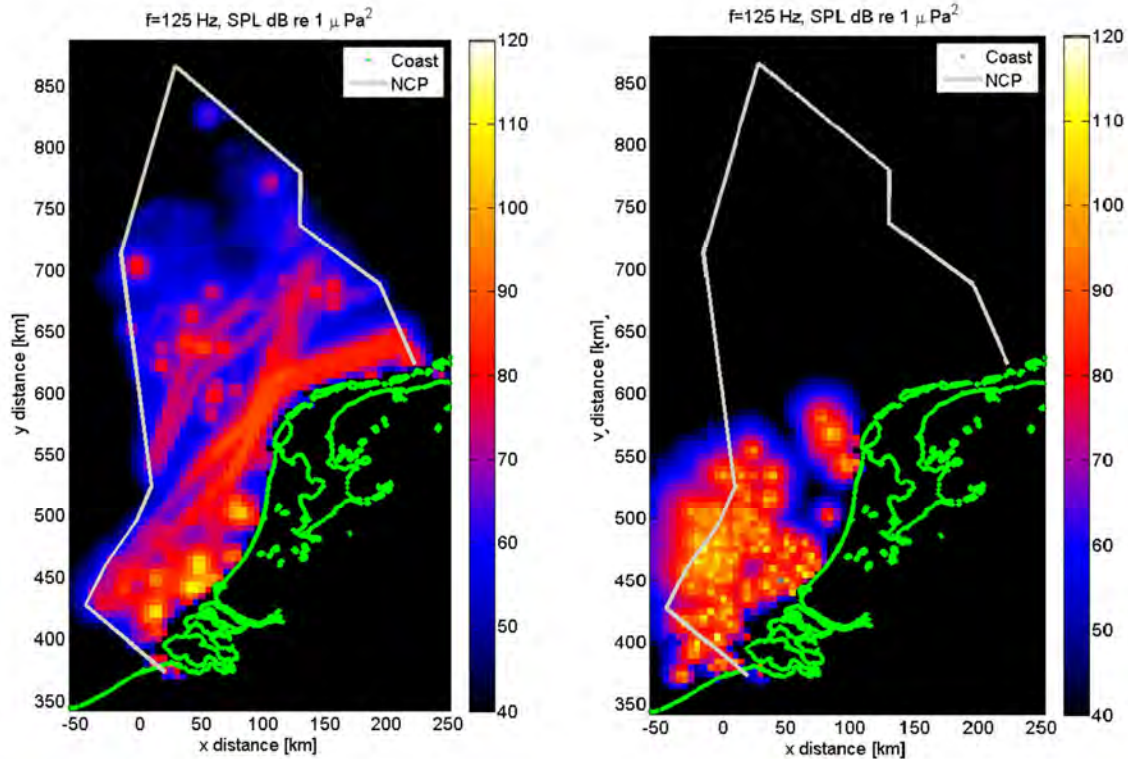


Figure 12: Annually averaged noise predictions for the Dutch North Sea: SPL in the decidecade centred at 125 Hz. Left: shipping noise for 2007; right: noise from explosions, averaged over two years (2010 and 2011). Receiver depth is 1 m. (provided by Özkan Sertlek (University of Leiden) and TNO, © Özkan Sertlek).

## Explosions

Approximately 230 underwater explosions took place in the Dutch North Sea in the period 1 Jan 2010 to 31 Dec 2011 (see Figure 9).

Explosions are concentrated in the southwest corner of the Dutch North Sea, where the predicted annual average contribution from explosions to the 125 Hz band is mostly between 70 dB and 110 dB re 1  $\mu$ Pa, compared to mostly 60 to 90 dB re 1  $\mu$ Pa from shipping in the same frequency band. If the predicted contribution at a given location is dominated by a single detonation, a one second average at that location will be 75 dB higher than this during the explosion (i.e., up to ca. 185 dB re 1  $\mu$ Pa in the same frequency band). The maximum SPL will depend on both the bandwidth and duration of the received pulse. A system designed to record such events in combination with the background noise would require a dynamic range of at least 110 dB. Conversely, a system designed to omit these high amplitude events would neglect the single largest contribution to Indicator 2 in the south-western part of the Dutch North Sea. This shows the need to store the complete distribution for the purpose of analysis.

### 2.3.4 Conclusions and way ahead

Noise maps similar to those presented can give a clear indication of the main anthropogenic sources that contribute to sound at each location. The two chosen activities take place mainly in the south and southwest of the Dutch North Sea, close to the coastline. Such maps can be used to identify:

- locations for which the soundscape is dominated by a single (and identifiable) anthropogenic source.
- locations at which the soundscape is dominated by multiple (identifiable) anthropogenic sources.
- locations where soundscape is dominated by natural sounds.

Applications include:

- choice of suitable locations for monitoring by measurement.
- choice of suitable locations for monitoring by modelling.
- design of suitable measurement and data acquisition equipment (e.g., the need for high dynamic range in areas with a high likelihood of explosions).

Important sound producing anthropogenic activities sources not included in the present maps are seismic surveys and offshore construction (mainly of wind farms).

One could use similar maps to calculate statistics of the spatial distribution, such as:

- arithmetic mean of squared sound pressure.
- a measure of spatial variability.
- the annually averaged total sound energy in the Dutch North Sea. By taking account of the propagation conditions, doing so would provide a ranking of sound sources in the Dutch North Sea of higher fidelity than that obtained by Ainslie *et al.* [2009] using the concept of free field energy [Ainslie & Dekeling, 2011]



## 2.4 Noise modelling and mapping in Irish waters

(Author: T. Folegot)

### Summary

The research programme STRIVE Noise, conducted by Quiet-Oceans (France) and CMRC (Ireland) and funded by the Irish EPA aims to provide a preliminary seasonal ambient noise atlas based on available environmental and anthropogenic data. Among this atlas of noise, specific sound maps associated with shipping has been produced based on an annual collection of Automated Identification System (AIS) data. While there was excellent agreement between modeled outputs and local in-situ acoustic validation data, uncertainty and variability of the environmental and anthropogenic parameters is taken into account by a Monté-Carlo approach. This enables the production of seasonal and statistical noise maps which describe, for each geographical location in the map, the probability to measure a given noise level in the form of percentiles.

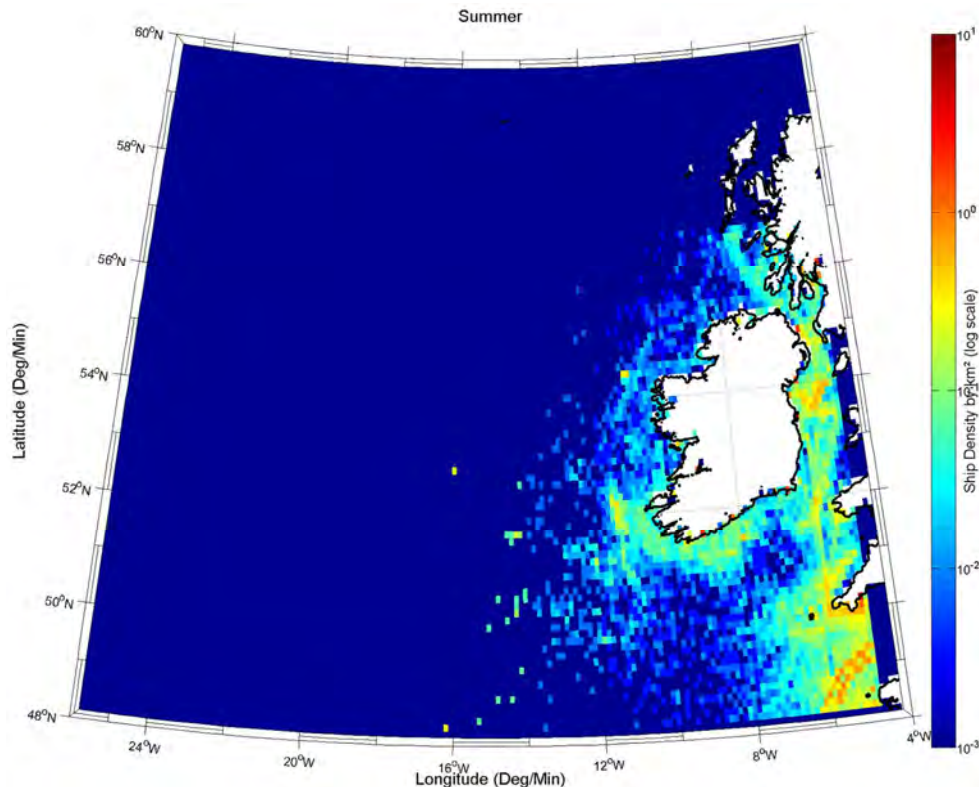
### 2.4.1 Method

The proprietary Quonops© ocean noise monitoring and prediction system (Folegot 2010) has been used to model soundscapes in Irish waters. The model domain ran from 3°–25° W longitude, and 46°–59° N latitude, utilizing a 0.5°x0.5° grid over the shelf and nearshore waters and 1°x1° in offshore waters. Quonops© uses a Monté-Carlo approach to determine the seasonal statistics of the sound fields, and describe the spatio-temporal distribution of noise levels generated by human activities across the Irish EEZ in terms of probability. The noise level distribution in the water column and sediments depends largely on the noise sources present, bathymetry, and environmental conditions including temperature, salinity, sea state, and sediment type. Therefore, these variables are included in the Quonops© modeling framework. Bathymetry data come from the freely available GEneral bathymetric Chart of the Oceans (GEBCO) database. Seabed sediment distribution data was sourced from the MESH Atlantic project ([www.meshatlantic.eu](http://www.meshatlantic.eu)) and matched with APL equivalents (APL 1994) for which specific sound absorption figures are available, based on expert knowledge. Sediment data was lacking for a proportion of cells, and these were allocated a nominal “sand” classification on the grounds that this sediment type dominated the offshore sediment types in the area for which data was available. Modeled data for temperature/salinity profiles were obtained from the Irish Marine Institute using the NE Atlantic oceanographic forecast model, which provides temperature/salinity profiles at 2km grid resolution. Seasonal wave heights across the model domain were computed from the HIPPOCAS hindcast data (Vijaykumar et al. 2004), with the mean value for each season used in unpopulated grid cells. In order to represent the spatial and temporal distribution of shipping traffic for noise modeling purposes, Automatic Identification System (AIS) data were obtained from the Department of Transport, Tourism and Sport, and processed to give ship density per km<sup>2</sup> for each season. For ships, sound sources were modeled as point sources near the surface using the Wales & Heitmeyer model.

An autonomous underwater sound recording device was deployed for 16 days outside Cork bay on the south coast of Ireland to accurately characterize the sound field and locally ground-truth the predictive sound maps produced by the model.

### 2.4.2 Shipping activities in Irish waters

The AIS network was able to report a semi-coastal description of vessel positions under the current year which requires AIS to be fitted aboard all ships of gross tonnage exceeding 300 engaged on international voyages, cargo ships of gross tonnage exceeding 500 not engaged in international voyages and all passenger ships irrespective of size. The AIS based data set is therefore not exhaustive, but gives a reasonable description of large shipping. A seasonal density map has been derived from the annual AIS dataset, and Figure 13 is an illustration of the shipping density corresponding to July-September 2012.



**Figure 13: Ship density map corresponding to the period July-September 2012, and based on the coastal AIS network. The colour scale unit is the average number of vessel present per square kilometre and is expressed in a logarithmic scale between  $10^{-3} \text{ km}^{-2}$  (deep blue) and  $10 \text{ km}^{-2}$  (deep red).**

### 2.4.3 Shipping noise mapping

The stochastic nature of noise is related to the fact that the sources of anthropogenic noise and, to a lesser extent, environmental conditions, are difficult to predict or to anticipate. It is difficult to predict number, type and position of ships in the area, although AIS gives a fair description of the spatial and temporal distribution over the year. Environmental uncertainty, such as weak or sparse data describing bottom properties, or variability such as fluctuating sea-state also usually leads to difficulties when it comes to characterization of the anthropogenic noise at the scale of a basin and a season.

To overcome these two difficulties, an approach based on Monte-Carlo has been proposed in order to build a statistical map of the anthropogenic noise, and to provide to the stakeholders a representative description of the seasonal and spatial variability at the scale of an oceanographic basin. The Monte-Carlo approach applied in this project consists of a number of releases of anthropogenic situations that are consistent with the statistical description given by the AIS data.

Based on the statistical environmental description of the Irish EEZ (oceanography, bathymetry, bottom properties, etc.), Quonops, Quiet-Oceans' ocean noise prediction system was able to calculate the noise field associated with each individual anthropogenic situations. From this set of "instantaneous" three-dimensional sound predictions, the noise statistics representative of the seasonal environment and the shipping variability has been derived in the form of percentiles. A percentile is describing, for each latitude and longitude of the map, the proportion of time and depth where the ambient noise is larger than a given value, and these are expressed according to the International Standard [ISO 1996-1:2003] as "N% exceedance levels". The 50% exceedance level is exactly the definition of the median.

The resulting noise maps for the Irish EEZ and representative of the summer are represented in Figure 14 for 1% (rare occurrence), 10% (significant occurrence), 50% (median occurrence) and 90% (most

occurrences) exceedance levels. The 1% exceedance level represents the highest noise levels that are expected, whereas the 90% exceedance level is close to the distribution of the lowest level of anthropogenic noise. It is interesting to note that the shipping route in the north-west corner of France contributes more to underwater sound levels than the routes that go to some harbours in the south coast of Ireland and the multiple routes in the Irish channel. It is also interesting to note the resurgence zone of ambient noise in the shallow waters in the north-west of Irish EEZ. Although this has to be confirmed by in-situ measurement, it could be explained by propagation effects linked to the bathymetric and oceanographic features of the area.

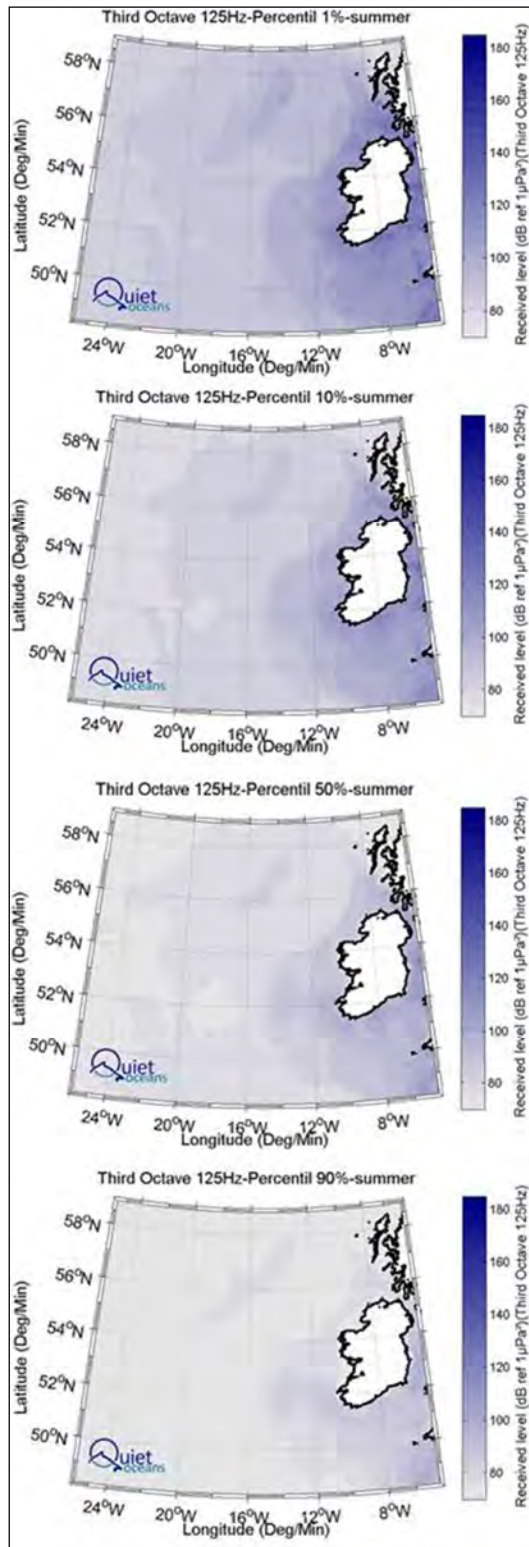


Figure 14: 125 Hz third-octave noise maps representative to shipping noise in summer for 1% (rare occurrence), 10% (significant occurrence), 50% (median occurrence) and 90% (most occurrences) exceedance levels. The 1% exceedance level represents the highest noise.

#### **2.4.4 Discussion**

Underwater sound propagates very rapidly (approx. 1500m per second), and over large distances at low frequencies (1000s of kilometres). Sound propagation in the ocean is largely dependent on the topography of the ocean floor, and the nature of the sediments (Guisse & Sabathié 1964). The modelled area of the Irish EEZ is bathymetrically complex, with strong contrasts between the relatively flat coastal shelf area, and large offshore features such as the Rockall trough, Porcupine Seabight and Hatton bank, all of which exert a significant influence on the resulting propagation patterns.

Although consistent with the scientific and technical state-of-the-art, the results are of a predictive nature and have only been calibrated against ocean acoustic field surveys in one part of the model domain (off Cork bay). While there was excellent agreement between modelled outputs and validation data, uncertainty in model parameters is taken into account by the Monté-Carlo approach. This enables parameters to be varied within a range of uncertainty. Whilst our approach also provides a reasonable description of shipping activities, it should not be regarded as a fully comprehensive description of all vessel traffic. The coastal AIS network cannot capture signals from vessels that are far from shore, resulting in offshore vessel movements being underrepresented, and the contribution from fishing vessels is likely to be underrepresented, as a (unknown) proportion may not operate AIS. However, model outputs represent a viable and feasible assessment of the propagation of underwater noise in the framework of the MSFD.

#### **2.4.5 Acknowledgements**

This research was undertaken in partnership with the Coastal and Marine Research Centre, University College Cork, Ireland, and financed through the Environmental Protection Agency Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007-2013, funded by the Irish Government under the National Development Plan 2007-2013.

## 2.5 BIAS - Baltic Sea Information on the Acoustic Soundscape

*(Authors: P. Sigray & M. Andersson)*

The Baltic Sea is a semi-enclosed ocean with nine states bordering the sea. It consists of eight sub-catchment areas (basins) and a numerous of harbours. The density of ships is one of the highest in Europe. It is estimated that about 2000 sizeable ships are at sea at any time. Further, several large wind farms are planned to be erected adding noise to the marine environment. Undoubtedly, due to the unbound character of noise it has to be dealt with and preferable on a regional scale.

In September 2012 the EU supported BIAS project was started (LIFE+ programme). The project has three main objectives. The first is to establish a regional implementation of Descriptor 11, which includes development of user-friendly tools for management of the Descriptor and to obtain sound levels. The second objective is to establish regional standards and methodologies that will allow for cross-border handling of data and results, which is necessary for an efficient joint management. The third objective is to model the soundscape and thereby expand the measurements to the entire Baltic Sea. Not at least, a regional handling will decrease the over-all costs to individual Member States.

The BIAS project is aimed at solving the major challenges when implementing Descriptor 11 in the Baltic Sea. One year of measurements will be performed covering the whole Baltic Sea. In total 40 sensors will be deployed. The measurements will be performed by adhering to the standards that will be established in the project. Likewise will the data be analysed using standardized signal processing routines. Results will be subjected to a quality control and finally stored in a common data-sharing platform.

The project has faced many of the challenges that arise when the Descriptor is to be transformed into daily practice. Consequently the BIAS project has gained valuable experience that can be shared with all Member States. For more details visit BIAS website where contact information can be found ([www.bias-project.eu](http://www.bias-project.eu)).



## 2.6 Noise modelling and mapping in German waters

(Author: S. Werner)

### 2.6.1 Objective

Acoustic mapping of noise levels arising from offshore human activities over scales relevant to long-term, regional-scale decision making would also allow a holistic assessment for D 11 MSFD.

A German research & development project (at the Federal Environment Agency (UBA)) is recently educing a mapping software (SEANAT-Subsea Environmental Acoustic Noise Assessment Tool). A modelling approach is used which is based on measurements of ambient noise and relevant sound sources. The software is created to allow for modelling of the underwater sound fields in the EEZs of the German Baltic and North Sea and imaging species-related impacts on organisms.

Software requirements were given beforehand, e.g.:

- 50 Hz to 20 kHz, 1/3 octave, 500 m resolution
- 3-D, sound speed profile and bottom variability
- SEL for impulse, SPL for continuous noise, several propagation models optional
- Digital bathymetrics
- List of target species, their audiograms (hearing threshold as a function of frequency), and regulator thresholds (e.g. for behavioural disturbance, temporary threshold shift)
- Evaluation against receiving properties of animals (audiograms)
- Supported by long time (abt. 3 month) monitoring in dedicated areas
- With input from other projects validation of propagation loss
- Determination of noise variability
- Proposal of recorder placement (5 in North Sea, 3 in Baltic Sea) preferably at existing stations

A first version of the SEANAT Software (Subsea Environmental Acoustic Noise Assessment Tool) is now available running on a JavaScript-enabled web browser to be accessed through a SEANAT user account.

The SEANAT system includes the following main components:

- Web-based graphical interface
- User-specific configuration and results files
- Databases of source spectra, environmental data, and model parameters
- A high-performance computing environment on which sound propagation models are run

### 2.6.2 Measurement standards, sound profiles, recordings of background noise

Sources and their signatures, align with respective measurement standards, are collected or measured if not available with the aim of producing a catalogue of relevant source signatures of those acoustic sources that are supposed to be incorporated in the mapping. Those include shipping, pile driving and seismic activities including predictions for their typical propagation loss. Information is collected on distribution, density and acoustic characteristics of human activities in European waters for multiple depths and frequencies (as part of a sound register). In addition features which lead to substantial variation of propagation loss are identified.

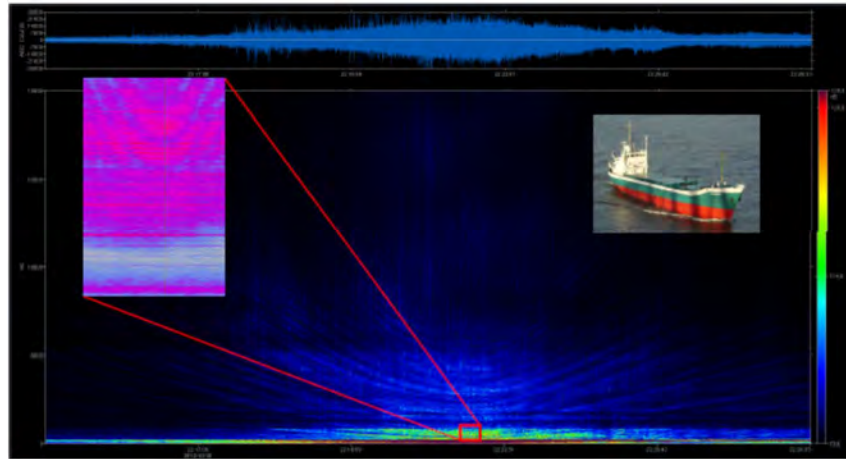


Figure 15: Spectrogram of passing ship, CPA at 0.3 nmi (@DW ShipConsult)

### 2.6.3 Definition of area-specific propagation models

Existing validated propagation models for the different marine regions as well as information on validated environmental data for European Seas (bathymetry, constitution of sediment, in situ-measurements of hydro-acoustic parameters etc.) were collected and factored for the definition of area-specific propagation models. SEANAT uses a modelling approach, where the propagation loss (PL) is calculated as a function of range, depth and frequency along radials from the source. PL is combined with the source spectrum to obtain received level as a function of range, depth and frequency along each radial. The results can be combined in a number of ways to obtain a variety of received level plots.

Following underlying propagation models were chosen for SEANAT and tested by evaluating passing ships:

For frequencies up to and including 2kHz:

- RAMGeo
- Parabolic equation model by Michael Collins, US Navy Research Laboratory
- Captures full wave acoustics
- Too slow at higher frequencies

For frequencies above 2kHz:

- BELLHOP
- Gaussian beam tracing model by Michael Porter, HLS Research
- Ignores wave diffraction effects so not accurate at low frequencies

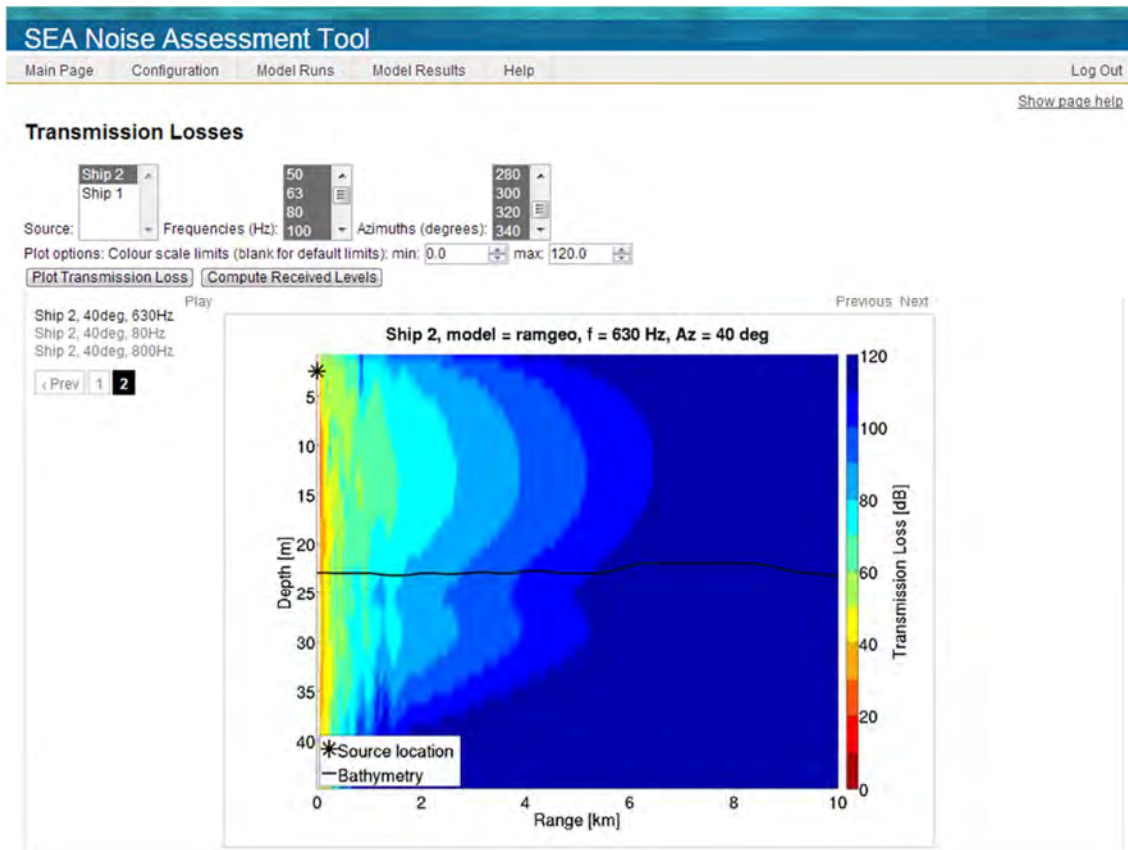


Figure 16: Example of plotted propagation loss results for computing received levels

#### 2.6.4 Status of work

Recorder with acoustic releaser were procured, placed in the Baltic and North Sea and recovered. AIS data for the Baltic Sea is already procured, the same will be done for the North Sea. Source spectra for pile driving and ships were generated and implemented in SEANAT. Water column sound speed profile were procured, selected and implemented in SEANAT as well as bottom acoustic data which was derived from pile driving signal characteristics.

A first version of the software is available, tests are ongoing. First species-specific sound levels for harbour porpoises to illustrate different zones of impacts (TTS, disturbance) are already incorporated in SEANAT. Other species including the possibility to compare their audiograms with received sound levels will be added.

Discussions have taken place with national experts and political decision-maker to meet their requirement and to ensure wide usage of the software once available for regular usage.

## 2.7 European experience with the use of mapping

(Author: Michael Dittrich)

The use of mapping has some history and in the process of implementing the MSFD we should make use of earlier European experience. Noise monitoring in air has been carried out for decades and has resulted in a body of work on noise maps. The relevant EU regulation is described in Part II, *Text Box 1*, and provides some useful background within Europe that can assist in implementing the MSFD.

European Directive 2002/49/EC [2002/49/EC], also known as the Environmental Noise Directive (END), regulates the assessment and management of environmental noise from large infrastructures including major agglomerations (>250 000 inhabitants), roads (> 6 million vehicle passages per year), railways (> 60 000 train passages per year) and major airports. The END is one of the instruments of Community policy to achieve a high level of health and environmental protection, in particular against noise. It requires these infrastructures to be assessed by producing revised noise maps every five years. In addition, action plans for noise mitigation must be compiled, aimed at reducing noise levels that exceed national limits set by individual MS. Both the noise maps and action plans are submitted to the European Commission (EC), which collects these in a database for evaluation purposes. The action plans must also be updated every five years and must take into account major changes affecting noise levels. The noise maps and action plans are publicly disseminated.

The noise indicators used for noise mapping are the day-evening-night level (Lden) and the night level (Lnight), both determined for a whole year. The noise levels may be determined by measurement or by calculation. The harmful effects of noise are determined by dose-effect relationships for annoyance and for sleep disturbance. By combining topographical data on location and numbers of inhabitants per dwelling, numbers of annoyed and sleep disturbed people can be estimated. The END does not set noise limits at the receiver locations, which is at the discretion of member states.

The END prescribes the following in its annexes:

- a. The definition of the noise indicators;
- b. The assessment methods for the indicators, both measurement and calculation;
- c. Assessment methods for harmful effects;
- d. Minimum requirements for strategic noise mapping and action plans
- e. Data to be sent to the Commission.

values of Lden and Lnight can be determined either by computation or by measurement (at the assessment position). Measurement methods must be adapted in accordance with the principles governing long-term average measurements stated in [ISO 1996-2] and [ISO 1996-1].

Recommended assessment methods are listed for member states that have no methods or wish to change their methods. Currently, the Commission is introducing new assessment methods into legislation known as CNOSSOS-EU. The assessment methods predict average noise levels at receiver positions based on noise source data and propagation models. The source data are typically derived from average sound emission data for characteristic vehicle groups (road or rail), their average speeds and operating conditions, the infrastructure (road type or track type for railways) and the flow rate of each vehicle group. For sound propagation, the basic geometry, ground absorption, reflections and noise barriers are taken into account. For noise mapping, generally total broadband Lden levels are used. But for more accurate assessment in relation to action plans, noise levels in octave bands are used.

The END was evaluated in 2010 [Rev 2002/49/EC 2010], to review the implementation of the key provisions of the Directive, to review measures employed to manage environmental noise from key sources, and to develop an Action Plan outlining further implementation strategies and Community action on environmental noise.

## 2.8 Comparison of averaging methods for Indicator 11.2.1

(Authors: M. A. Ainslie, M. van der Schaar, M. André, S. P. Robinson & M. K. Prior<sup>13</sup>)

### Summary

The purpose of section 2.8 is to substantiate the advice of TSG Noise to MS on the choice of annual averaging method for implementation of Indicator 11.2.1 (henceforth abbreviated as «Indicator 2»). Because no suitable data are available in European waters, it was decided to compare different averaging methods on a data from the International Monitoring System of the Comprehensive Test Ban Treaty Organization (CTBTO), made available to TSG Noise via LIDO. The definition of «ambient noise» is discussed in sec 2.8.2, followed by a description of the CTBTO data set (2.8.3) and a comparison of different averages (2.8.4). The advantages and disadvantages of each averaging method are listed in sec 2.8.5 and discussed in 2.8.6. The conclusions (2.8.7) depend on one's chosen definition of «ambient noise». TSG Noise recommends (see sec 2.8.8) use of the arithmetic mean (AM).

### 2.8.1 Introduction

The MSFD defines GES (partly) in terms of Indicator 11.2.1. This Indicator (henceforth “Indicator 2”) requires a measure of annually averaged noise. The purpose of this memo is to consider pros and cons of different kinds of averaging. Indicator 2 is specified by the Commission Decision of Sep 2010 as “Trends in the ambient noise level ... [... average noise level ... over a year]”, which is interpreted by the TSG Noise report of February 2012 as: “Trends in the annual average of the squared sound pressure associated with ambient noise ... expressed as a level in decibels”.

The purpose of this memo is to reconsider this definition. It does so by comparing the annual average (arithmetic mean) of the squared sound pressure with other possible metrics. Specifically, we consider processing by which the mean square sound pressure is determined in successive samples (“snapshots”) of duration  $T$ . A distribution of snapshots with fixed  $T$  is then obtained by collecting them over one or more consecutive years. The following three averages of this distribution are considered:

- Arithmetic mean (AM - the TSG interpretation);
- Geometric mean (GM - equivalent to the average of individual SPL values in decibels);
- Median.

The possible benefits of a fourth type of average, the mode, are considered in sections 5.6.5 to 5.6.7.

The purpose of Indicator 2 is to quantify noise in a frequency range likely to be influenced by shipping. Shipping noise has both permanent and intermittent components, and an annual average will automatically include both. There might also be locations at which shipping noise is not the largest contributor to Indicator 2.

The choice of averaging method needs to be:

- I. robust to minor changes or differences in implementation;
- II. physically meaningful and representative of a large enough region to justify its use as an indicator of GES;
- III. practical (simple to implement);
- IV. compatible with comparable regulations or procedures (desirable property but not essential).

It seems likely that Indicator 2 will be monitored by different Member States (MS) with different equipment and different analysis protocols, and that the selection of equipment and protocol is unlikely to be fixed for all time. We therefore seek an average that is robust to small differences and changes in equipment and processing protocols. We used CTBTO data, which were analysed with a software package from the LIDO-project (Listening to the Deep Ocean Environment) [André *et al.*, 2011].

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<sup>13</sup> The views expressed in this paper are those of the author and do not necessarily reflect those of the CTBTO Preparatory Commission.

The remainder of this chapter concentrates mainly on requirement (I), the invariance with the choice of snapshot duration. The other two requirements are addressed in the discussion section. The LIDO data that were used for this memo had been analysed in time segments of 65.5 seconds. The minimum snapshot duration used here is therefore 65.5 seconds. Noise measurements were provided as sound pressure levels over the data segment. Longer snapshots were made by combining the SPL measurements of multiple consecutive data segments. This means that the averages other than the AM were influenced by the AM that is already part of the SPL computation. The use of a 65.5 second snapshot time in this document is not intended as a recommendation from the authors; it was chosen with a different application in mind, namely the detection of certain cetaceans. A similar analysis on the same recordings, using a smaller snapshot time (10 seconds) is provided in van der Schaar *et al.* [2013].

## 2.8.2 Definitions of “ambient noise”

Indicator 2 is defined as a trend in annually averaged ambient noise, so it is important to have definitions for the terms “trend” and “ambient noise”.

The term “ambient noise” is defined by TSG [Van der Graaf *et al.*, 2012, Annex 3 (Glossary)] as *“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.”*

This definition is accompanied by the note: *“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 part II chapter 2 where the definition of [ambient noise] is explained.”

The opening paragraph of Van der Graaf *et al.* [2012] Sec. 4.1 reads:

*“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 a more operational definition of sound relevant to indicator 11.2.1 that is more in line with the term ‘soundscape’ (see [IQOE] 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.”*

With this definition, “ambient noise” is all sound except self-noise, including infrequent transients, consistent with the definition ANSI 1994; (‘all sound’ includes both natural and anthropogenic sounds).

### TREND

TSG Noise defines “trend”, as that by Van der Graaf *et al.* [2012]:

*“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”*

## 2.8.3 CTBTO data set

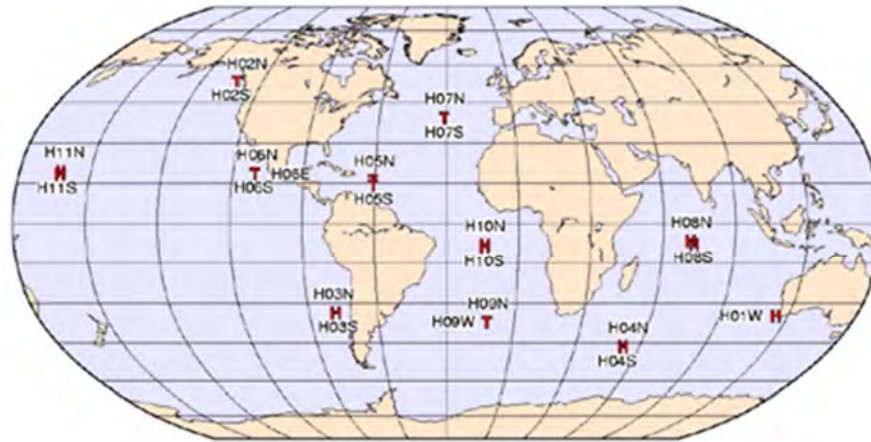
Data are available from CTBTO over several years (see Figure 17 for the location of the hydrophone stations and Table 6 for start and end date of data used from each station). One channel of each station was analysed for a period of at least three years. The analysis was done in data segments<sup>14</sup> of duration

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<sup>14</sup> A single CTBTO data segment contains 16384 samples at a sampling rate of 250 Hz.



~65.5 seconds. For each segment the mean square pressure was computed in the third octave band centred at 63 Hz. In the following this quantity, expressed as a level in decibels, is denoted  $SPL_{63}$ . The digitisation sensitivity in the last column is defined as the ratio of the digital representation of a sound pressure sample, as recorded by CTBTO, to the acoustic pressure giving rise to that sample.



The IMS hydroacoustic network consists of 6 hydrophone triad stations and 5 land-based (so-called) T-stations

Figure 17: Location of CTBTO stations.

Platform	Hydrophone station #	Time start	Time end	# Segments (duration 65.5 s)	# Days	Digitisation sensitivity [counts per millipascal]
Cape Leeuwin	H01	Jan 2008	Jun 2011	1580682	1189	1.83918
Juan Fernández Islands	H03	Jan 2007	Feb 2010	1459911	1098	1.77996
Ascension Island	H10	Jan 2008	Jun 2011	1650629	1242	1.82815
Wake Island	H11	Jan 2008	Jun 2011	1650603	1242	1.82715

Table 6: Summary of CTBTO data set.

Measured values of  $SPL_{63}$  exceeding 180 dB re 1  $\mu$ Pa were removed from the data set on the assumption that they are probable acquisition artefacts. Measurements from each station are described below.

## ASCENSION ISLAND

At Ascension Island (Figure 18) the distribution of the level stayed mostly the same throughout the years (Figure 19).



Figure 18: Location of Ascension Island (hydrophone station H10).

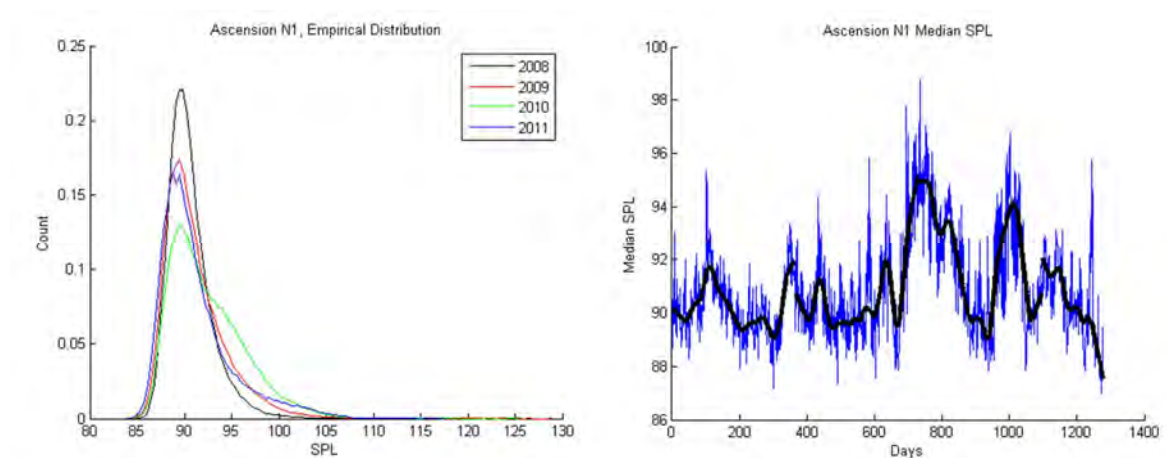


Figure 19: Left graph: Histogram of  $SPL_{63}$  distribution for Ascension Island ( $T = 65.5$  s); right graph: daily median of  $SPL_{63}$  vs time.

In 2010 data for Ascension Island, around day 750, a temporal increase in noise can be seen. The station had a characteristic noise pattern from a seismic survey (Figure 20).

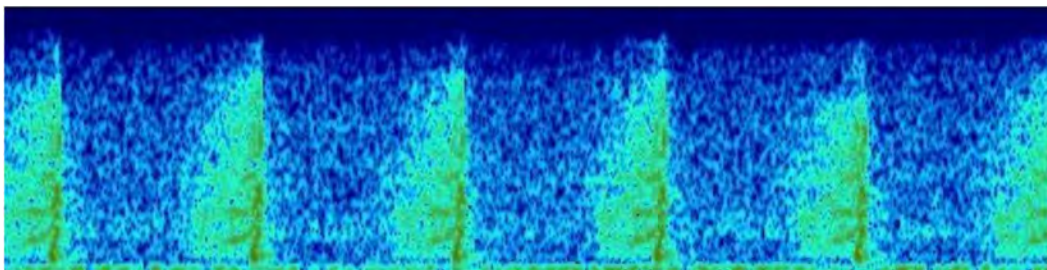


Figure 20: Spectrogram recorded on June 30 2010, from 15:39:55 to 15:41:00 (UTC) for Ascension Island; this is one sample of 65.5 s duration.

## CAPE LEEUWIN

At Cape Leeuwin (Figure 21) a change in noise levels could be measured (Figure 22). But from 2011 only the first half of the year was available which seems to be the noisiest season and will offset the distribution.



Figure 21: Location of St Alouarn Islands, close to Cape Leeuwin (hydrophone station H01). Well placed for ice noise from Antarctica.

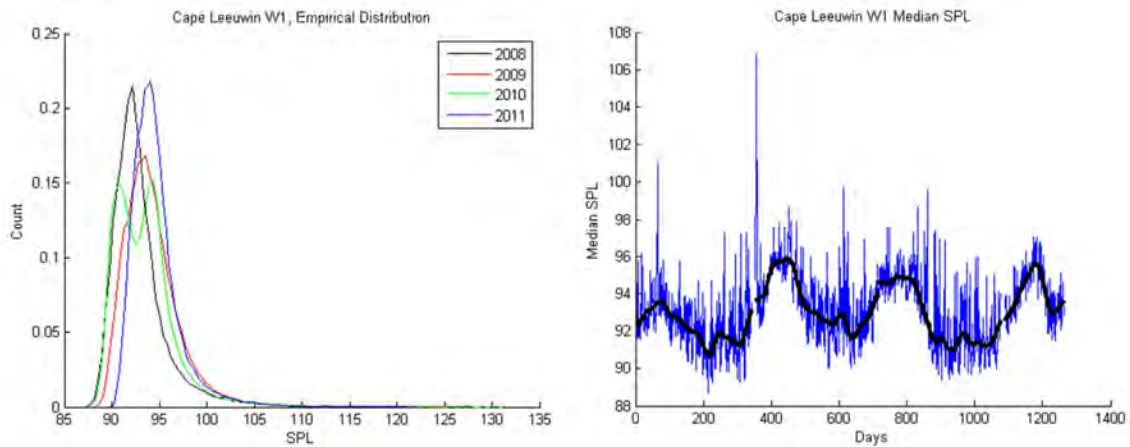


Figure 22: Left graph: Histogram of  $SPL_{63}$  distribution for Cape Leeuwin ( $T = 65.5$  s); right graph: daily median of  $SPL_{63}$  vs time.

Figures 23 and 24 show evidence of ice noise at ca. 21:00 on 14 May 2011 (although the highest amplitude events on that day seem to be those of 14:40 and 23:05).



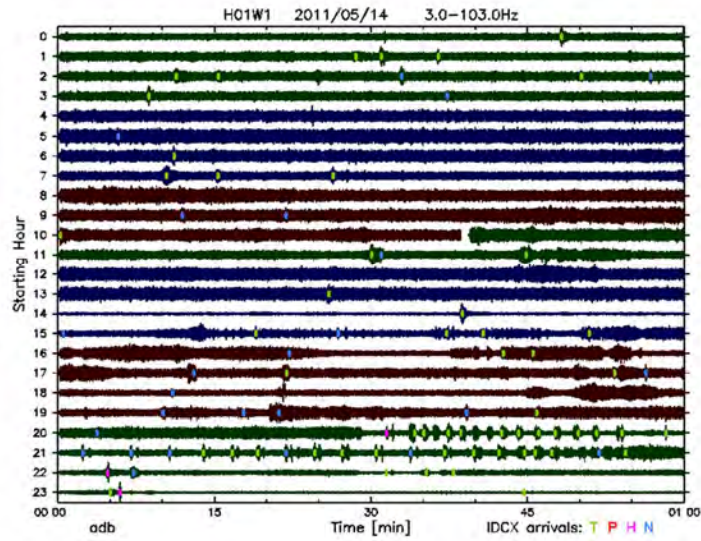


Figure 23: Broadband (3 Hz to 103 Hz) pressure time series (24 h) for Cape Leeuwin.

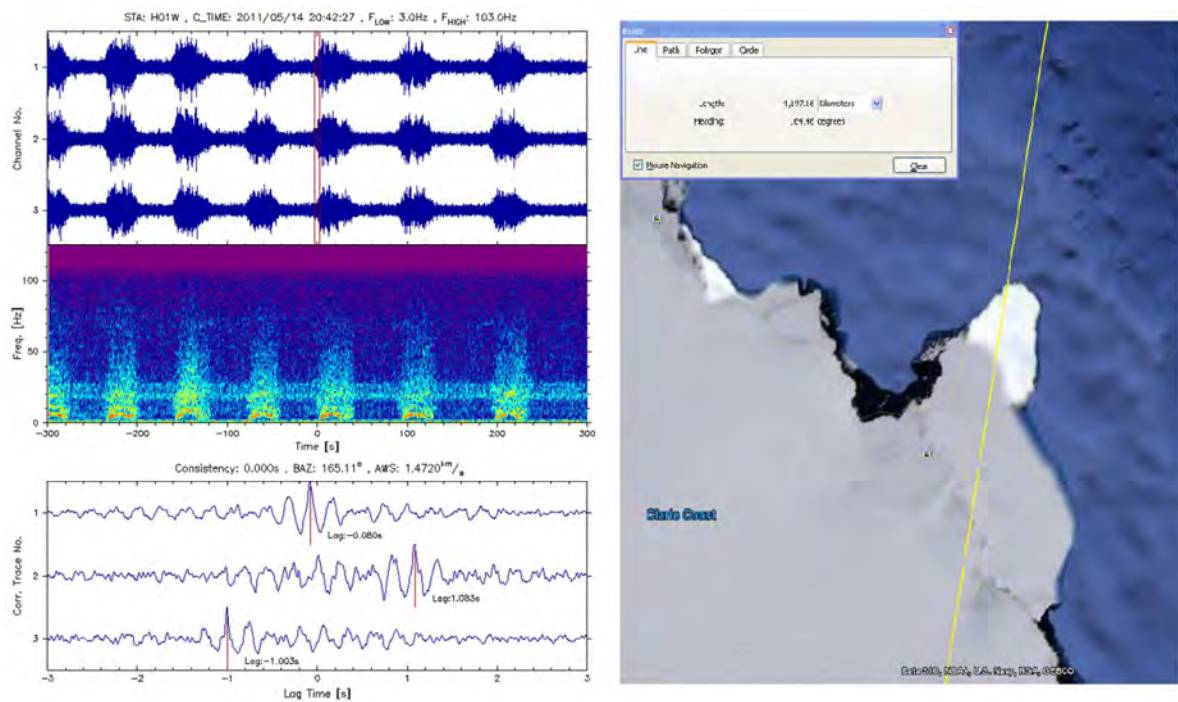


Figure 24: Left: Close-up of broadband (3 Hz to 103 Hz) pressure time series and spectrogram at 20:42:27 ± 300 s on 14 May 2011 for Cape Leeuwin; lower graph shows time lag plot indicating sound originates from bearing 165 deg. Right: Ice tongue on Antarctica at bearing 165.

### JUAN FERNÁNDEZ ISLANDS

The noise levels at Juan Fernández (Figure 25) were measured to be more or less the same throughout the year (Figure 26).



Figure 25: Location of Juan Fernández Islands (hydrophone station H03).

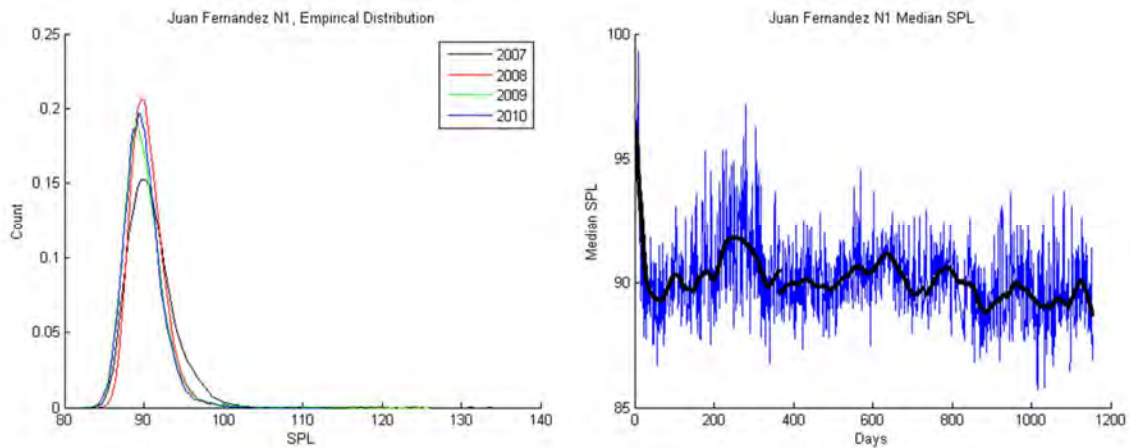


Figure 26: Left graph: Histogram of  $SPL_{63}$  distribution for Juan Fernández Islands ( $T = 65.5$  s); daily median of  $SPL_{63}$  vs time.

### WAKE ISLAND

As with Cape Leeuwin, a strong seasonal cycle at Wake Island (Figure 27) gives rise to an almost bimodal distribution of the sound levels. Since only the first six months of 2011 were available its distribution was more unimodal.



Figure 27: Location of Wake Island (hydrophone station H11), well placed for the Tohoku earthquake.

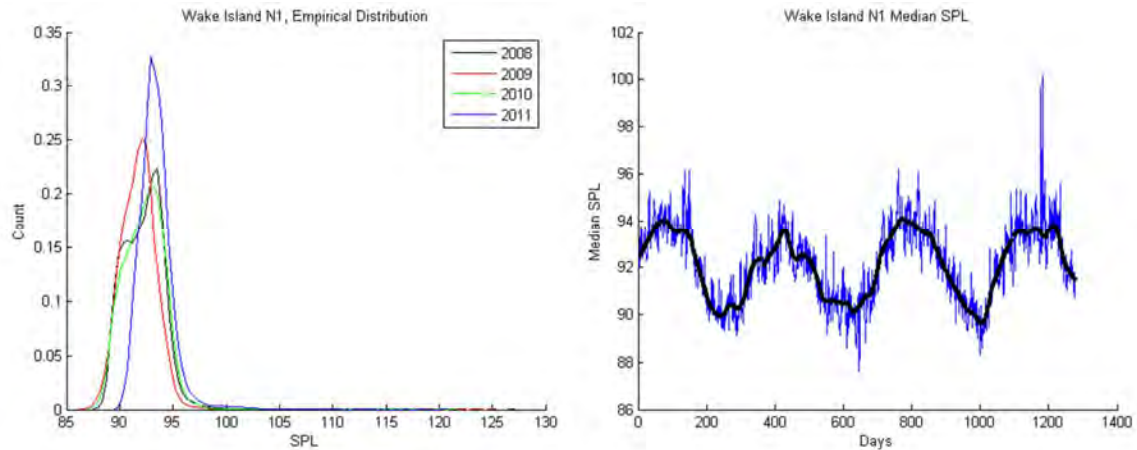


Figure 28: Left graph: Histogram of  $SPL_{63}$  distribution for Wake Island ( $T = 65.5$  s); daily median of  $SPL_{63}$  vs time.

The sharp peak ca. day 1200 (Fig. 28) corresponds to an earthquake of 11 March 2011 at Tohoku and its aftershocks. Figure 28 shows the time series recorded by the Wake Island hydrophone (H11) two days after the earthquake illustrating these aftershocks. The purpose of Figures 29 and 30, and later figures examining the possible causes of individual events, is to provide insights that would help assess the possible relevance of such events to masking.



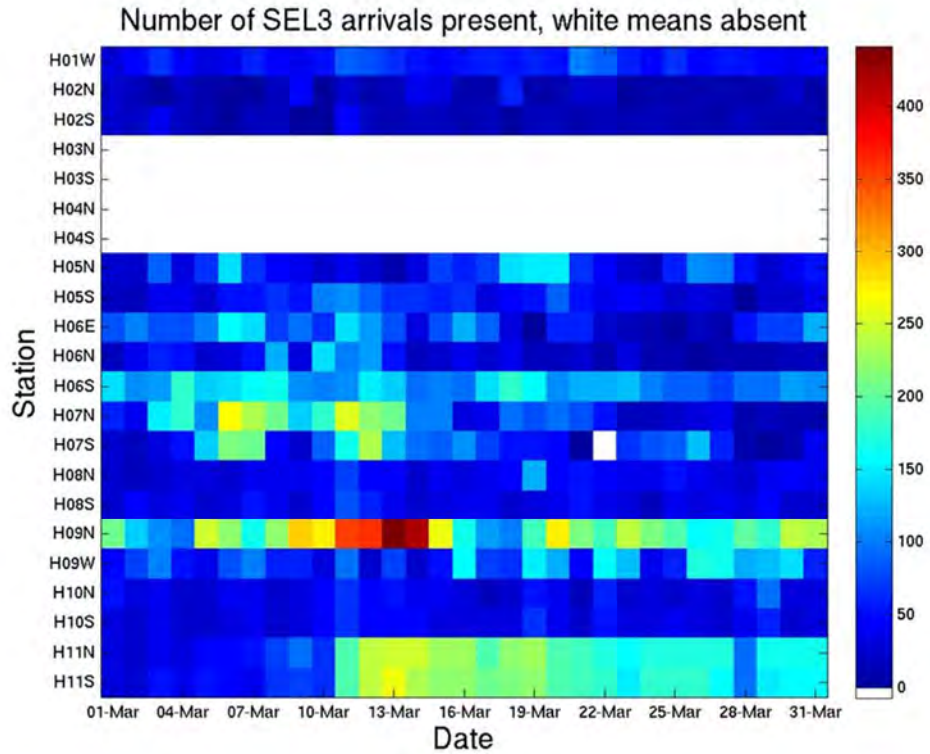


Figure 29: T: The abrupt increase of activity at H11 (Wake Island) on 11 March 2011, caused by the Tohoku earthquake.

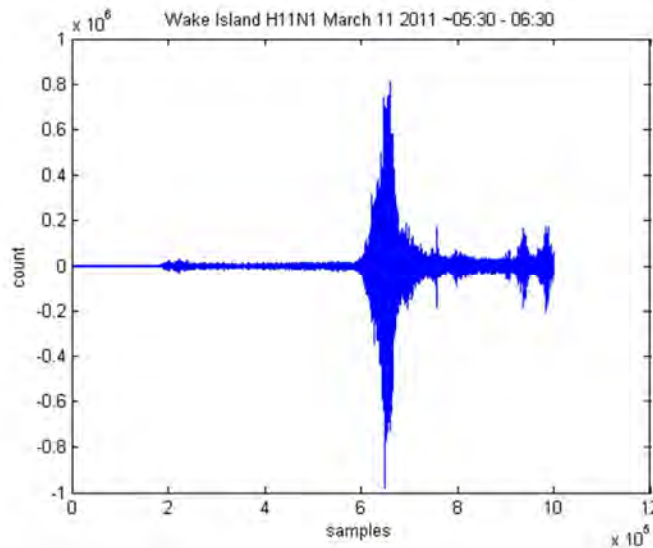


Figure 30: Broadband pressure signature on H11 (Wake Island) caused by Tohoku earthquake on 11 March 2011. The maximum sound pressure magnitude corresponds to a sound pressure of -550 Pa ( $-10^6$  counts, with a sensitivity of 1.83 counts per millipascal).

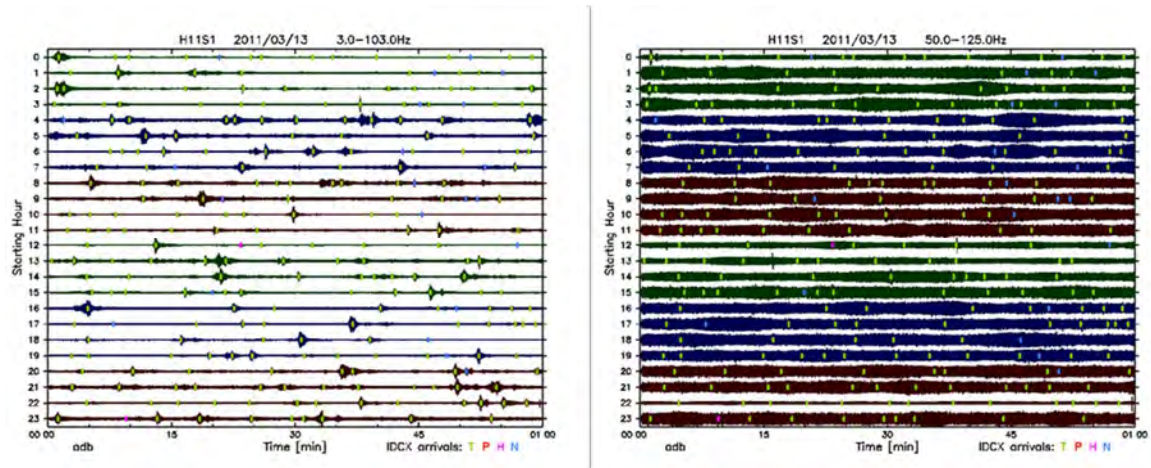


Figure 31: Pressure time series (24 h) for Wake Island on 13 March 2011. Left: broadband (3 Hz to 103 Hz); right: filtered in the frequency band 50 Hz to 125 Hz.

### 2.8.4 Annual averages

Different systems are likely to use different segment durations, so it is important to look at the effect of changing the averaging time. The term “snapshot” is adopted to mean a collection of one or more segments combined together for the purpose of evaluating the mean square pressure. The snapshot duration ( $T$ ) is an integer multiple of the segment duration (in this case 65.5 s). For each snapshot duration, the number of snapshots in a year is approximately  $365.25 \text{ days}/T$ .

Four types of annual average are considered, arithmetic mean, geometric mean, median and mode. The median, denoted  $L_M(T)$ , is the median of all  $\text{SPL}_{63}$  snapshots of averaging time  $T$ . The mode is the value that appears most often in a set of data. The arithmetic and geometric means are defined as follows.

First the arithmetic mean  $A(T)$  is

$$A(T) \equiv \frac{1}{N(T)} \sum_{n=1}^{N(T)} P_n(T)$$

where  $N(T)$  is the number of snapshots of duration  $T$  in one year (on the assumption that the data are continuous, containing no gaps for an entire year).

$$N(T) = \frac{1 \text{ year}}{T}$$

and  $P_n(T)$  is the mean square sound pressure (in 63 Hz band) of the  $n$ th snapshot of duration  $T$ .

The arithmetic mean is expressed as SPL in dB re 1  $\mu\text{Pa}$  (the level of the mean square sound pressure) using

$$L_A(T) \equiv 10 \log_{10} \frac{A(T)}{P_{\text{ref}}^2},$$

where  $p_{\text{ref}} = 1 \mu\text{Pa}$ .

The geometric mean  $G(T)$  is

$$G(T) \equiv \left( \prod_{n=1}^{N(T)} P_n(T) \right)^{1/N(T)}.$$

The geometric mean is expressed as the average SPL value in dB re 1  $\mu\text{Pa}$  using (mean of individual SPL values)

$$L_G(T) \equiv 10 \log_{10} \frac{G(T)}{P_{\text{ref}}^2}.$$

To examine how sensitive these averages are to the snapshot duration  $T$ , each of the averages vs sample duration is plotted in Figure 32. It can be seen that that  $L_A$  is independent of snapshot duration (as it theoretically should), while the other two averages vary with sample duration by up to 1.7 dB ( $L_M$ ) and 0.8 dB ( $L_G$ ). This variation can be examined in more detail by looking at differences relative to  $L_A$  and this is done in Figure 33 all averages tend to  $L_A$  for long sample duration. Snapshot durations  $< 65.5$  s, not considered here, would lead to larger differences.

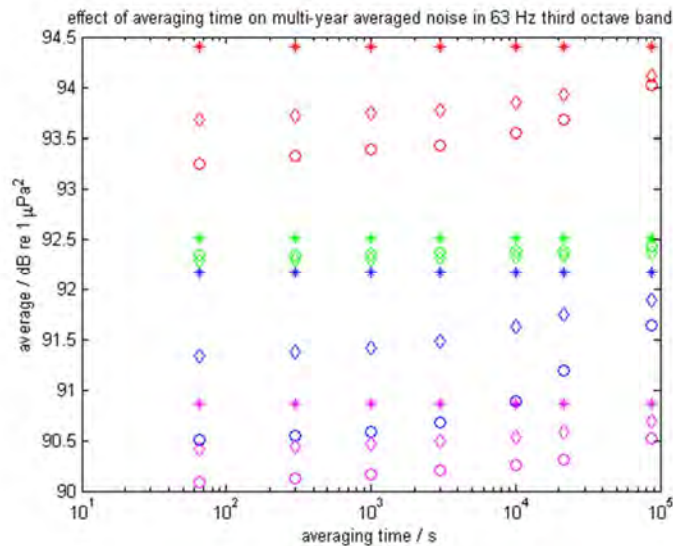


Figure 32: Arithmetic mean (asterisks), geometric mean (diamonds) and median (circles) plotted vs snapshot duration for four CTBTO sites; colours: Ascension Island, Cape Leeuwin, Wake Island, Juan Fernández. The averaging times (snapshot durations) are 65 s, 300 s, 1000 s, 3000 s, 10000 s, 21600 s and 86400 s.

Next we plot the levels relative to the arithmetic mean.

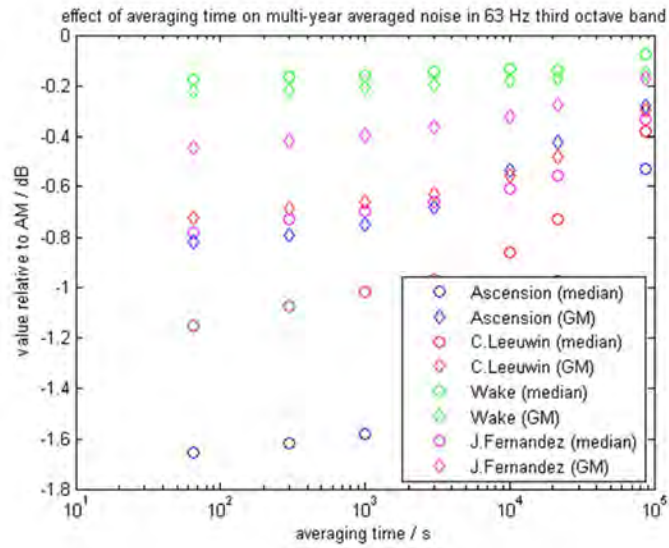


Figure 33: Differences  $L_G - L_A$  and  $L_M - L_A$  vs snapshot duration for four CTBTO sites; change seems to accelerate (increase in slope) for  $T > 1$  hour; at least for Cape Leeuwin and Ascension Is. colours: Ascension Island, Cape Leeuwin, Wake Island, Juan Fernández.

### 2.8.5 Pros and cons

	PROS	CONS
<b>Median</b>	<p>Representative of “background noise” if one wishes to exclude infrequent excursions from an otherwise stable background.</p> <p>Moderate dynamic range requirement</p>	<p>Sensitive to changes or differences in sample duration. Excludes high amplitude excursions that might contribute to total noise</p> <p>Incompatible with Leq metric of air acoustics</p> <p>Cannot be predicted using annually averaged properties of sound sources</p> <p>Uncertainty calculations for the median are less straightforward and tend to lead to larger values than for the mean (for the same population) making the median less discriminating in detection of trends</p>
<b>Arithmetic mean</b>	<p>Robust to changes or differences in sample duration</p> <p>Can be predicted using annually averaged properties of sound sources</p> <p>Compatible with Leq metric of air acoustics</p> <p>Representative of mean acoustic power</p>	<p>Sensitive to outliers (extreme high values) caused by probable acquisition or processing artefacts</p> <p>Well-established metrics calculating uncertainty (variance, etc), although these tend to work better for a Gaussian distribution, which is not expected</p> <p>Requires high dynamic range to capture extreme (high) values</p>
<b>Geometric mean</b>	<p>Representative of “background noise” if one wishes to exclude infrequent (high) excursions from stable background</p>	<p>Sensitive to changes or differences in sample duration. Cannot be predicted using annually averaged properties of sound sources.</p> <p>Incompatible with Leq metric of air acoustics</p> <p>Sensitive to outliers (extreme low values) caused by measurement error.</p> <p>Requires high dynamic range to capture extreme (low) values</p>
<b>Mode</b>	<p>Representative of “background noise” if one wishes to exclude infrequent excursions from a stable background.</p> <p>Represents the most likely level</p>	<p>Sensitive to changes or differences in sample duration, and to the choice of bin size.</p> <p>Cannot be predicted using annually averaged properties of sound sources.</p> <p>Incompatible with Leq metric of air acoustics.</p> <p>Unstable if the distribution contains two or more peaks (e.g. for a bimodal distribution with two different values that are equally probable)</p>

Table 7: Summary of pros and cons.

### 2.8.6 Discussion

The four requirements for an averaging method are addressed below:

#### Robust to minor changes or differences in implementation

For the measurements from CTBTO stations presented in this memo, dependence on snapshot duration of  $L_M$  is up to 1.7 dB and of  $L_G$  up to 0.8 dB (the largest values both occurring for Ascension Island). Variations depend on site, with the smallest variation occurring for Wake Island (up to about 0.2 dB).

Measurements reported by [Merchant *et al.*, 2012] show greater sensitivity in an area close to a heavy shipping lane (and therefore more relevant to Indicator 2), with a dependence of  $L_M$  on snapshot duration up to 15 dB and of  $L_G$  up to 14 dB.

More important than the magnitude of the difference between  $L_A$  and  $L_M$  is the year to year variability in this difference. The measurements reported in [Van der Schaar *et al.*, 2013] demonstrate year to year changes between 0.9 dB (Wake Island) and 3.8 dB (Ascension Island).

The value of  $L_A$  is always independent of snapshot duration. To obtain an average that is independent of snapshot duration using a geometric mean (GM) or median requires a snapshot duration exceeding  $10^5$  s (ca. 1 day). Such a long averaging time is not considered practical. An arithmetic mean (AM) is the only kind of average that is robust to the choice of snapshot duration for short snapshots. An additional advantage of AM is that it can be predicted using annually averaged properties of the main sound sources. Use of AM would also permit comparison with other data sets (e.g., CTBTO or US data), likely to use a different snapshot duration than EU MS. The main disadvantages of AM are its sensitivity to high outliers caused by measurement error or equipment failure and the requirement for a high dynamic range to capture high amplitude events. While this is a disadvantage requiring high end recorders, it is an advantage from the biological point of view. High amplitude events, even if very short, are very meaningful from an acoustic ecology perspective and their potential for negative effects in marine life. Correctly quantifying the energy contribution of such events must be an important condition for the correct implementation of Indicator 11.2.1.

### Physically meaningful and representative of a large enough region to justify its use as an indicator of GES

It can be argued that infrequent sounds are less likely to affect GES than frequent ones. By infrequent we mean sounds that from an animal's perspective appear as individual events i.e. the response to one sound is not influenced by the response to the previous occurrence of sound of that type. For example, an infrequent sound is unlikely to cause a displacement response because although it may cause startle or injury, a consistent flight response is only likely to occur if the sound is repeated within a certain time period. For example, animals do not generally flee from a single explosion but may be displaced by a seismic survey. For Indicator 2 our interest is in masking, for which it might be appropriate to discard some infrequent sounds.

For example, if one wished to exclude rare events similar to the Tohoku earthquake (see Figure 22), partial or complete exclusion of infrequent sounds can be achieved by means of the GM or median. The risk of doing so is that one might unwittingly exclude sounds of direct relevance to GES (the passage of one ferry per hour might be the only source of anthropogenic sound in an otherwise quiet background; a 3-month long seismic survey that raises the background by 30 dB during that period would be excluded). Overall, the monitoring should aim to distinguish natural and anthropogenic sounds to the extent possible but where this is not possible it is important not to bias ambient noise measurements with infrequent events (as defined above). This requires an averaging method that does not give undue influence to infrequent events but still needs to provide sufficient data to identify that these have occurred (e.g. comparing AM to median).

One can also argue that the physically meaningful quantity is mean square sound pressure if we are interested in the average acoustic power. This would be in line with common practice in air acoustics ISO 1966, where the concept of "Leq" is used for long-term averages of a sound pressure time series, with the values transformed into decibels only after averaging. If the data are available in decibel form (as might be the case if measured using a sound level meter), these must first be converted to pascals squared before averaging and then transformed back to dB afterward [ISO 1996-1:2003]. Essentially, use of an arithmetic mean would be equivalent to an Leq approach, as adopted also, as an interim measure, by CetSound [Gisiner 2012] "The physics and biology of underwater sound make it difficult to come up with a universal metric; [received sound pressure level, sound exposure level], band-averaged weighting or



other metrics all fall short under certain contexts. It is sufficient for now that Leq can serve as a kind of ‘straw man [proposal]’ for weighting the pros and cons of alternatives”.<sup>15</sup>

The requirement for Indicator 2 to be representative of a “large region” leads potentially to a need for multiple monitoring locations.

A complete description of the acoustic conditions would need to include both the (yet to be defined) general background level and the contribution of higher intensity events that are significant to the GES regardless of their frequency of occurrence. Loud, impulsive noises can have severe impacts on marine life but - if infrequent enough - might make a negligible contribution to the averaged sound field. Different averages will be more or less sensitive to occasional loud signals but any over-arching description of the acoustic conditions in an area should be sensitive to such signals because they form an important part of those conditions. Conversely, if the sounds are infrequent but still influence the mean, they would have been high intensity events. Therefore, the difference between the AM and the median might be a way of determining the potential for occasional acute effects.

While it is not obvious how this should be done, if the masking background can be represented by one of the higher exceedance levels, a possible way ahead is suggested by [ISO 1996-1:2003], which defines “residual sound”, one of three “sound designations”, as (emphasis added).

**Residual sound:** total sound remaining at a given position in a given situation when the **specific sounds** under consideration are suppressed

The other two sound designations are:

**Specific sound:** component of the **total sound** that can be specifically identified and which is associated with a specific source,

and

**total sound:** totally encompassing in a given situation at a given time, usually composed of sound from many sources near and far

A similar definition of “residual sound” is provided by [ANSI 1988], including the following clarifying note: “Residual sound may be approximated by the percentile sound level exceeded during 90-95 percent of the measurement period.”

Also defined by [ISO 1996-1:2003] is the **N percent exceedance level:** “time-weighted and frequency-weighted sound pressure level that is exceeded for N % of the time interval considered”

[Miksis-Olds *et al.*, 2013] presents a statistical analysis of changes in ambient sound in the frequency range 10-105 Hz at Diego Garcia, in the Indian Ocean between 2002 and 2012. Using a 1 minute snapshot duration, the authors of that paper calculate ten-year trends in the 1 %, 10 %, 50 %, 90 % and 99 % exceedance levels. There are two hydrophones at Diego Garcia, one north of the island and one south. At the southern hydrophone (right-hand graphs, Figure 31), Miksis-Olds *et al* find a consistent increasing trend of order 1.5 dB per decade, except at the 1 % exceedance level (1 % highest intensity), for which no significant trend is visible. At the northern hydrophone (left-hand graphs, Figure 31), there are also clear trends, but the direction (increasing or decreasing) depends on the chosen percentile. The higher

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<sup>15</sup> A “straw man proposal” is a simple draft proposal intended to generate discussion of its disadvantages and to provoke the generation of new and better proposals. For more explanation and examples, see [http://en.wikipedia.org/wiki/Straw\\_man\\_proposal](http://en.wikipedia.org/wiki/Straw_man_proposal)

exceedance levels (99 % and 90 %, corresponding to P1 and P10 in the graph, close to the noise floor) tend to increase with increasing time, while the lower exceedance levels (1 % and 10 %, corresponding to P99 and P90 in the graph, close to the noise ceiling) tend to decrease, with no visible trend in the median (50 % exceedance level). This figure demonstrates the importance of standardising on the statistical processing as well as on equipment and measurements.

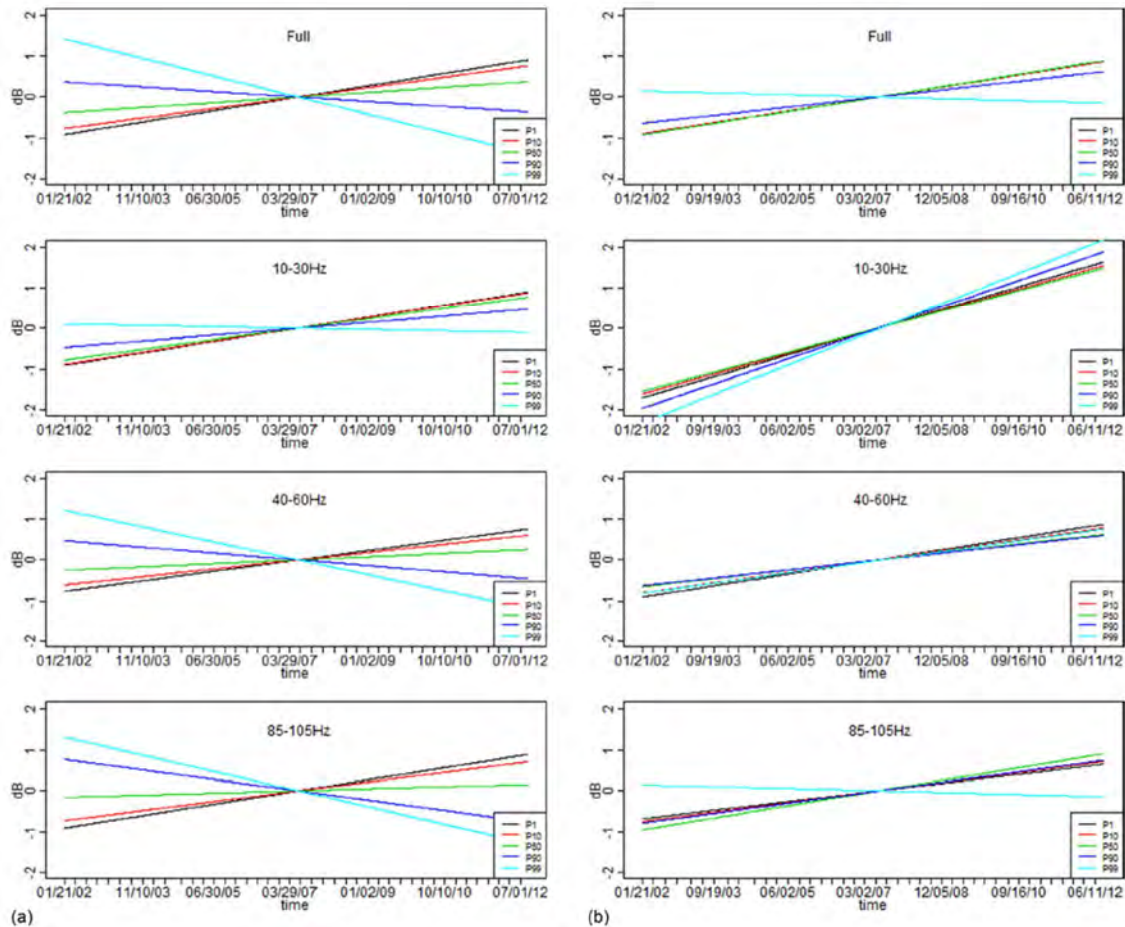


Figure 34 Summary of linear trends for the full spectrum and 20-Hz band analyses from the (A) North (N1) and (B) South (S2) locations. [Miksis-Olds *et al.*, 2013]

### Practical (simple to implement)

Any of the four averages considered (AM, GM, median or mode) is simple to implement from the point of view of a single monitoring location, if a data series of SPL snapshots vs time is available at that location. But to claim to monitor GES there is potentially a need for many monitoring stations. We do not expect the number of measurement stations to be large, and the only practical method to extrapolate from a small number of measurements to a large number of monitoring points is through modelling. Any of the averages can be calculated in principle using a computer model of the fluctuating noise field, with which fluctuations due to moving or intermittent sources are then modelled. A sequence in time of the desired duration (for Indicator 2 this would be one year) can be calculated and used to synthesise an annual snapshot distribution, from which the desired statistics can be computed. In practice the large amount of computation required for this approach might cause difficulties. A more practical approach is to average the source distribution over a year and use this average source distribution directly to predict the annually averaged squared sound pressure. Only the AM can be calculated in this way.

## Compatibility with comparable regulations or procedures

While compatibility with procedures followed by others is not considered essential, it is at least desirable. Of particular relevance are:

- international standards or agreements for sound in air (e.g. END or ISO 1996/ANSI for residual sound)
- US Cetacean and Sound Mapping ‘CetSound’ project [NOAA 2012]

The European Noise Directive uses the AM (in the form of an annually averaged  $L_{eq}$ ) for airborne noise. The US CetSound project has adopted the AM as an interim measure, pending further research.

The ANSI definition of “residual sound” is used by [ref Fristrup *et al.*, pp. 50-53, for sound in air] to justify the 90 percent exceedance level as a measure of “residual or background sound level”. For application to underwater noise, a choice of snapshot duration and percent exceedance level would be needed.

### 2.8.7 Conclusions

The conclusions depend on one’s interpretation of “ambient noise” as follows.

#### Conclusion 1: Use arithmetic mean

AM is the only type of average that for short snapshot durations is compatible with the Feb 2012 TSG definition of ambient noise and robust to differences or changes in snapshot duration. It is also compatible with the annual average noise level required by the Environmental Noise Directive, as well as the “straw man proposal” adopted by Cetsound [Gisiner 2012].

The main disadvantage of AM is its sensitivity to infinities in the data.

Use of the AM follows from the TSG definition. Care is needed to avoid measurement error and equipment failure. This will ensure all sounds are included, both natural and anthropogenic, regardless of their duration, intensity or frequency of occurrence.

#### Conclusion 2: Use mode

An alternative definition of “ambient noise” as the most likely value leads to the mode. The mode, like the median and GM, depends on the snapshot duration. If one wishes to exclude infrequent sounds from the definition of ambient noise, a possible way of achieving this is by use of the mode. The snapshot duration would need to be chosen carefully to avoid losing the baby with the bathwater. This duration would need to be a constant in order to establish a trend. Infrequent sound events that might be relevant to the GES might be misrepresented.

#### Conclusion 3: Use a fixed percentile or distribution of percentiles

An example of a fixed percentile is the median. This quantity is sometimes used [Andrew *et al.*, 2011, Merchant *et al.*, 2012, Van der Schaar *et al.*, 2013], but the present authors are not aware of a definition of “ambient noise” that would lead to the adoption of median as a metric. The main benefits of the median are its robustness and its low dynamic range requirement.

To the extent that computer modelling is used to monitor ambient noise, use of a fixed percentile (or mode) requires high fidelity predictions of the snapshot distribution resulting from fluctuations in time,

which is likely to result in a heavier computational problem, requiring a more complicated computer model, or longer computation time or both.

If one were to define “ambient noise” as “residual noise”, then according to ANSI this quantity can be estimated, for sound in air, using the 90 percent exceedance level.

If one requires a metric relevant to chronic effect and wishes to exclude infrequent sounds, the best way to facilitate this is to retain not only the complete probability distribution, but also the time series of SPL snapshots that results in that distribution (because we don’t yet know what to calculate, and the separation in time between successive events might be important).

### 2.8.8 Recommendation

What we seek is a metric of continuous ambient noise that reflects cumulative chronic effects of shipping noise. Research is needed to identify the nature and frequency of occurrence of sounds leading to relevant chronic effects. As an initial measure, TSG Noise advises MS to adopt the arithmetic mean (AM). The main considerations in reaching this recommendation are:

- a) the AM includes all sounds, so there is no risk of neglecting important ones.
- b) the AM is independent of snapshot duration.

The trend is the trend in the AM.

In order to establish the statistical significance of this trend, additional statistical information about the distribution is necessary. The rationale that led to Indicator 11.2.1 was associated with a concern that anthropogenic noise might mask important acoustic cues [Tasker *et al.*, 2010]. The duration of the period of (relative) silence between intermittent sounds is an important parameter in determining potential for masking. If the ambient noise includes loud transient sounds (airgun pulses, passing ships, etc), the potential for masking of these sounds is limited to some extent by the duration of the relatively quiet periods between these transients. If we retain only an amplitude distribution we lose this information.

For this reason, TSG Noise considers that information about time dependence is needed in addition to an amplitude distribution. Therefore, TSG Noise recommends that the complete distribution be retained in the form of sound pressure level as a function of time, with an averaging time to be specified. If it is not possible to store the full time series, TSG Noise advises to retain the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration (see also 2.8.4). TSG Noise advises MS to use a snapshot duration not exceeding one minute.

## 2.9 Experience from other projects

(Author: J.F. Borsani)

### Ligurian Sea (Mediterranean Sea) long-term low-frequency monitoring (1999-2002).

From 31 August 1999 to 7 September 2002 autonomous recorders (called “Pop-Ups”) were deployed in the Ligurian Sea. The deployments were part of a collaborative study between ICRAM – the Italian Central Institute for Marine Research (now ISPRA) and the Bioacoustics Research Project of Cornell University, USA. Eighteen autonomous recorders, sampling in ranges from 1 kHz to 2 kHz were deployed at water depths between a few tens of metres and 1421m. A total of 15 720 hours of sound recordings were extracted. Several lessons with respect to a) deployment techniques and b) analysis methods were learnt. Scientific results are summarized in Clark *et al.* [2002] and Borsani *et al.* [2008].

Recommendations made by [Borsani *et al.*, 2008] include:

- 1) Small hydrophone arrays (e.g. 3-4 elements) perform better than single recording units (noise reduction, range and direction finding up to a certain degree depending on array aperture);
- 2) The deeper the hydrophones are deployed, the better, although there might be an issue with calibration for deep hydrophones (minimizes surface noise, avoids low-frequency cut off, prevents collisions, minimizes risk of trawling and accidental removal);
- 3) Free mooring lines of at least 10 m with kit weighing a maximum of 20 kg in air must be provided (prevents kit from banging on sea bottom);
- 4) Soft anchors (e.g., sandbags) are better than discrete anchors with chains (minimizes self-noise of the mooring, minimizes the risk of drifting and melts with the substrate);
- 5) “Silent” mooring is mandatory (all metal or hard plastic parts must be embedded in rubber to avoid self-noise and corrosion)
- 6) Solid state drives are better than hard disk drives (no spin-up noise and low power drain, equals longer duration)
- 7) At the same cost of deployment, a higher sampling rate is achievable if a statistically robust duty cycle is applied (e.g., for shipping noise 1 hour on – 11 hours off)
- 8) Continuous recording of at least 60 minutes in a row is desirable; duty cycling may be appropriate (usually 60 minutes comprise a whole ship passage as well as small bits of ambient noise levels).
- 9) Archival recorders have the draw-back of being at risk of data-loss. In addition, huge data sets produced as a result of long deployments pose a serious challenge to IT resources as well as to staff. The road of real-time or delayed time data transmission is promising and must be explored.
- 10) If analysis is done manually 1 hour of recordings @ 2 kHz signal recording can take up to 3-5 hours for analysis and reporting; automatic or semi-automatic systems mitigate this but need frequent maintenance and instructions.

## 2.10 Rate of the increase of 63 Hz band underwater noise in the Pacific Ocean

(Author: M.A. Ainslie)

### Summary

The purpose of this section is to quantify the rate of increase of ambient noise based on available measurements since the 1960s. Because no suitable data are available in European waters, the data used are taken from [Andrew et al. 2011], for the north-east Pacific Ocean. Conclusions are listed in the final sub-chapter.

### 2.10.1 Introduction

The Commission Decision of 2010 [EC, 2010] proposes to determine trends in ambient noise. In this note an estimate is provided of the rate of increase of sound pressure level (SPL) at 63 Hz third-octave band in the northeast Pacific based on the measurements described by [Andrew *et al.*, 2011].

### 2.10.2 Overview of available data

The following table lists the spectral density levels (SDLs) reported in Table II from Andrew *et al.* [2011] in the 63 Hz third octave band<sup>16</sup> for measurements carried out ca. 1965 (column 2) and ca. 2000 (column 4). The SDL is converted to SPL in columns 3 and 5. The increase (difference between 2000 and 1965 values) is listed in column 6.

system	Wenz (ca 1965)		APL UW (ca 2000)		increase
	SDL / dB re 1 $\mu\text{Pa}^2/\text{Hz}$	SPL / dB re 1 $\mu\text{Pa}$	SDL / dB re 1 $\mu\text{Pa}^2/\text{Hz}$	SPL / dB re 1 $\mu\text{Pa}$	total (per decade) / dB
<b>d (Point Sur)</b>	82.0	93.6	87.0	98.6	5.0 (1.4)
<b>f (San Nicolas Island)</b>	74.4	86.0	80.5	92.1	6.1 (1.7)
<b>g (near northern California)</b>	79.2	90.8	81.8	93.4	2.6 (0.7)
<b>h</b>	82.0	93.6	87.7	99.3	5.7 (1.6)
<b>average</b>	<b>80.3</b>	<b>91.9</b>	<b>85.3</b>	<b>96.9</b>	5.0 (1.4)

**Table 8: Spectral density levels (SDLs); Andrew et al. [2011] in the 63 Hz third octave band for measurements carried out ca. 1965 (column 2) and ca. 2000 (column 4).**

Measurements are reported for four deep water sites in the northeast Pacific Ocean. Spatial averages (across the 4 sites) are calculated using a linear average in mean square pressure “average”. For this row the “increase” column shows the increase in the average (and not the average of the 4 separate increases, which is 4.9 dB).

The averaging methods applied by Wenz and APL are not identical. APL calculates a median, which is sensitive to the snapshot duration (163.84 s)<sup>17</sup>, while Wenz calculates a geometric mean after removing outliers. According to Andrew *et al.* [2011], this process is approximately equivalent to the median. The snapshot duration used by Wenz is ca 200 s.

<sup>16</sup> The values at 125 Hz are not included in Table II of Andrew *et al.*

<sup>17</sup> The averaging procedure is described on p643.



Both the median and geometric mean (GM) underestimate the true sound pressure level, which by definition is calculated using an arithmetic mean (AM) of the squared pressure samples. The difference between the median (or GM) and the AM depends on the details of the distribution. For CTBTO sites it is between 1 dB and 6 dB, the averaged difference between the GM and the AM is approximately 2.25 dB [Van der Schaar *et al.*, 2013, Marine Systems (submitted)].

### **2.10.3 Conclusions**

- The difference of 5 dB in 35 years amounts to 1.4 dB per decade on average, in deep water.
- A similar trend can be expected in deep water in other parts of the industrialised world. It is not possible to confirm this expectation by measurements in European waters because it is about the last 35 years of the 20th Century, for which no suitable measurements are known to the authors. It might be possible to do so by means of a hind cast with a validated computer model.
- In shallow water the trend is likely to be different. There is no information available on whether this trend is likely to be greater or less than 1.4 dB/decade in shallow water.
- Spatial variation in SPL at 63 Hz across these deep water sites is ca 8 dB. In shallow water the variation it is likely to be greater than in deep water.

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## List of Symbols, Acronyms and Abbreviations

SYMBOLS, ACRONYMS AND ABBREVIATIONS	DESCRIPTION
<b>ADC</b>	Analogue to Digital Converter
<b>ADD</b>	Acoustic Deterrent Device
<b>AHD</b>	Acoustic Harassment Device
<b>AIS</b>	Automatic Identification Systems
<b>AM</b>	Arithmetic mean - the TSG Noise interpretation
<b>ANSI</b>	American National Standards Institute
<b>APL UW</b>	Applied Physics Laboratory, University of Washington (USA)
<b>ASA</b>	Acoustical Society of America
<b>BIAS</b>	Baltic Sea Information on the Acoustic Soundscape
<b>BOEM</b>	Bureau of Ocean Energy Management (USA)
<b>CD</b>	Commission Decision 2010/477/EU
<b>CMRC (Ireland)</b>	Coastal and Marine Research Centre, Ireland
<b>CNOSSOS-EU</b>	Common Noise Assessment Methods of the European Union
<b>CS</b>	cylindrical spreading
<b>CTBTO</b>	<u>Preparatory Commission</u> for the Comprehensive Nuclear-Test-Ban Treaty Organization / in part 2 as: Comprehensive Nuclear-Test-Ban Treaty Organization
<b>dB</b>	decibel, the most generally used logarithmic scale for describing sound
<b>DECC</b>	Department of Energy and Climate Change (UK)
<b>DG ENV</b>	Directorate General on Environment of the European Commission
<b>EC</b>	European Commission
<b>EEZ</b>	Exclusive Economic Zones
$E_{\text{hammer}}$	Hammer energy
<b>EIA</b>	Environmental Impact Assessment
<b>END</b>	Environmental Noise Directive: European Directive 2002/49/EC [2002/49/EC]
<b>EU</b>	European Union
<b>EUCC</b>	Coastal & Marine Union (EUCC)
<b>GCS European 1950</b>	GCS, GEOGCS (Geographic Coordinate System)
<b>GES</b>	Good Environmental Status as defined in the MSFD
<b>GM</b>	Geometric mean (- equivalent to average in decibels)
<b>h</b>	hours
<b>H#</b>	CTBTO hydrophone station, no. #
<b>Hz</b>	hertz, the SI unit of frequency defined as the number of cycles per second of a periodic phenomenon
<b>ICES</b>	International Council for the Exploration of the Sea
<b>ICRAM</b>	Italian Central Institute for Marine Research (now ISPRA)
<b>IEC</b>	International Electrotechnical Commission
<b>IEC 60565-2006</b>	Norm: Underwater acoustics - Hydrophones - Calibration in the frequency range 0,01 Hz to 1 MHz
<b>IMARES</b>	Institute for Marine Resources & Ecosystem Studies, Wageningen, NL
<b>IQOE</b>	International Quiet Ocean Experiment
<b>Irish EPA</b>	Environmental Protection Agency, Ireland
<b>ISO</b>	International Organization for Standardization
<b>JNCC</b>	Joint Nature Conservation Committee (UK)
<b>LIDO</b>	Listening to the Deep-Ocean Environment
<b>LIFE+ programme</b>	Regulation (EC) No 614/2007 of the European Parliament and of the Council of 23 May 2007 concerning the Financial Instrument for the Environment (LIFE+)
<b>log</b>	logarithm
<b>MPA</b>	Marine Protected Areas
<b>MS</b>	Member State (of the EU)
<b>MSFD</b>	Marine Strategy Framework Directive, 2008/56/EC
$m_{\text{TNTeq}}$	TNT equivalent charge mass
<b>nmi</b>	Nautical mile (1 nmi = 1852 m)

SYMBOLS, ACRONYMS AND ABBREVIATIONS	DESCRIPTION
NOAA	U.S. National Oceanic and Atmospheric Administration
NRC	National Research Center (USA)
NW-Europe	North-West Europe
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
PL	propagation loss
Quonops	Ocean Noise Anthropogenic Forecasting Platform
RL	Received Level
RMS	Root mean square
RNLN	Royal Netherlands Navy
$R_{ps}$	ranges where response is relevant
RWS	Rijkswaterstaat (NL)
SDL	spectral density level
SEL	sound exposure level
SEAMARCO	Sea Mammal Research Company
SI	The International System of Units
SL	source level
$SL_E$	energy source level
$SL_{zp}$	zero to peak source level
SPL	sound pressure level
STRIVE Noise	Science, Technology, Research and Innovation for the Environment
$T$	snapshot duration
TG11	Task Group of Descriptor 11 (Noise/Energy) of the MSFD (EC Decision 2010/477/EU)
TNO	Netherlands Organization for Applied Scientific Research (NL)
TNT	Trinitrotoluene, $C_6H_2(NO_2)_3CH_3$
TSG Noise (TSGN)	EU Technical Subgroup on Noise
TTS	temporary hearing threshold shift
UBA	Umweltbundesamt: Federal Environment Agency, Germany
UK	United Kingdom
US CetSound	"As a result, two data and product-driven working groups were convened in January 2011: the Underwater Sound-field Mapping Working Group (SoundMap) and the Cetacean Density and Distribution Mapping Working Group (CetMap). The overarching effort of both Working Groups is referred to as CetSound.
VMS	Vessel monitoring system
WG GES	EU Working Group Good Environmental Status
WGS84	World Geodetic System, the reference coordinate system WGS 84 is used by the Global Positioning System.
$\mu Pa$	Micropascal

Note: The SI units and unit symbols that are used in this report are not repeated in the list above, these are followed according to BIPM SI brochure (8<sup>th</sup> edition), available from <http://www.bipm.org/en/si/>.

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Abstract

This document has been prepared by the Technical Subgroup on Underwater Noise and other forms of Energy (TSG Noise), established in 2010 by the Marine Directors, i.e. the representatives of directorates or units in European Union Member States, Accessing Countries, Candidate Countries and EFTA Member States dealing with or responsible for marine issues. In December 2011, the Marine Directors requested the TSG Noise to provide monitoring guidance that could be used by Member States in establishing monitoring schemes to meet the needs of the Marine Strategy Framework Directive indicators for underwater noise in their marine waters. This document presents background information and annexes, is not part of the guidance, but is added for additional information, examples and references that support the implementation of the practical guidance to commence the monitoring required for underwater noise.

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